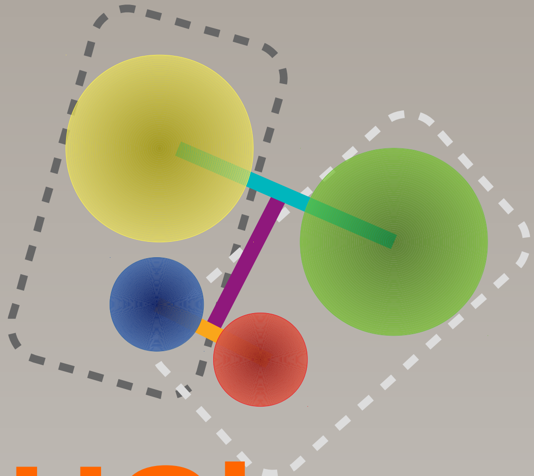


Recent LHCb results on exotic meson candidates

Ivan Polyakov

Syracuse University

on behalf of LHCb collaboration

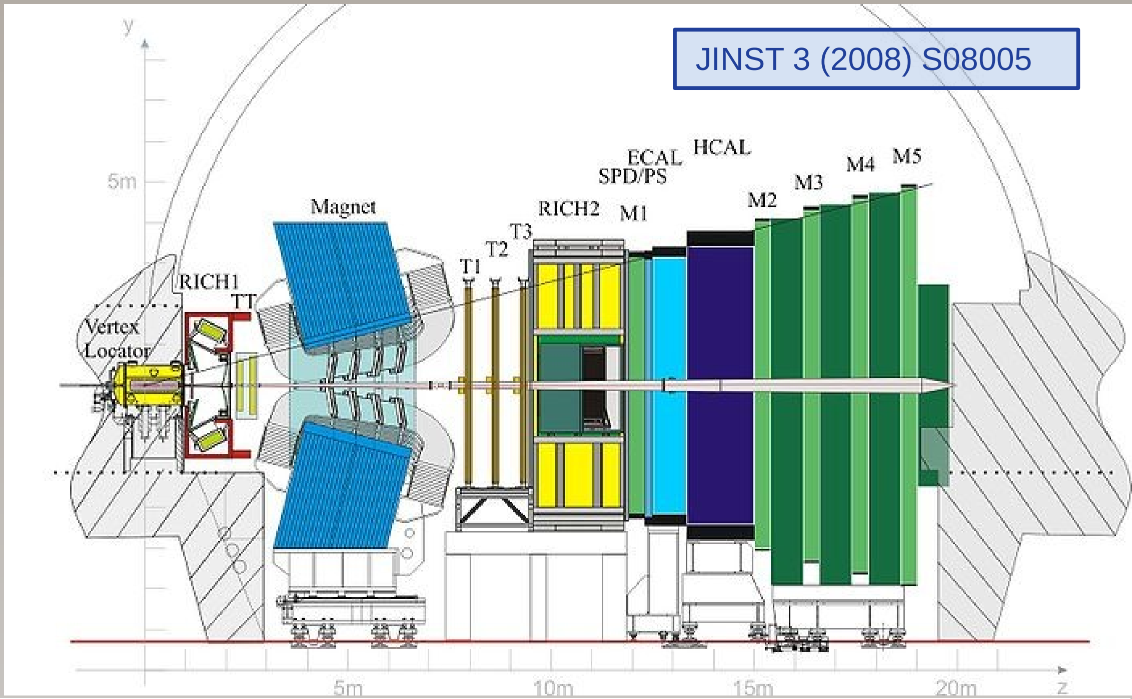
EPS-HEP, 29 July 2021

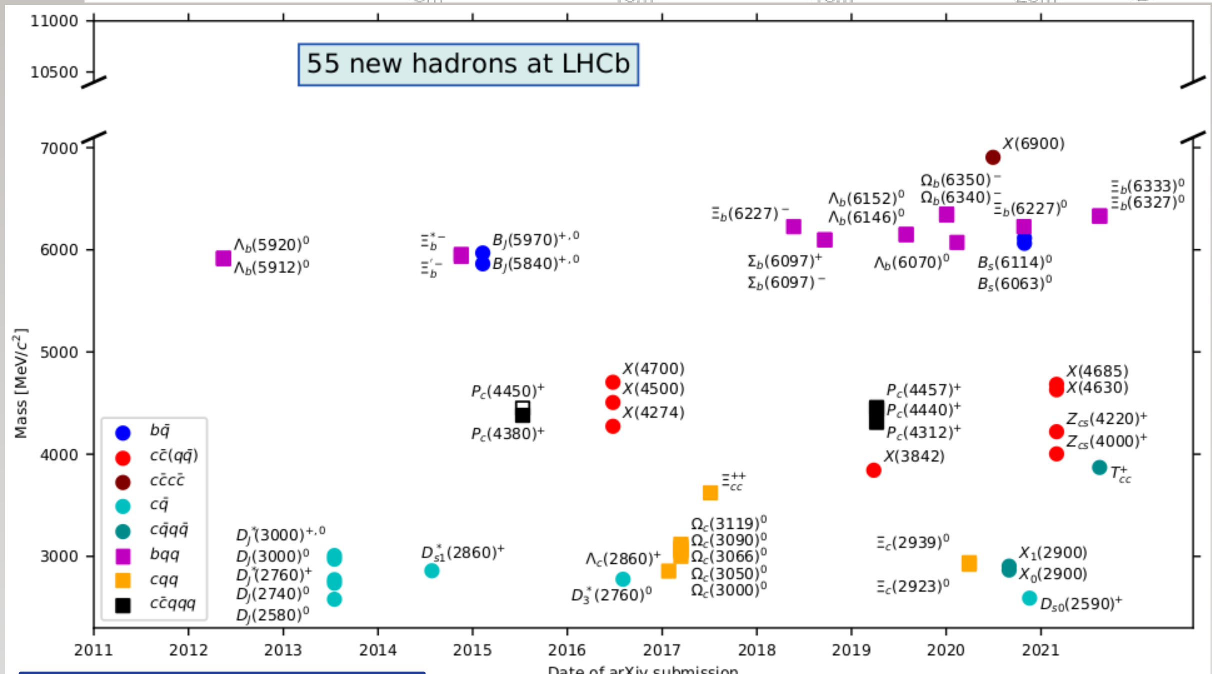
The LHCb detector

- Heavy hadron spectroscopy is a powerful tool for understanding how QCD works at "atomic" scale

- LHCb - forward spectrometer at LHC with excellent
  - momenta/mass,
  - vertex/time resolution
  - particle identification (K/π/p/μ)

very powerful tool for heavy hadron spectroscopy → contribute to major part of hadrons discovered at LHC





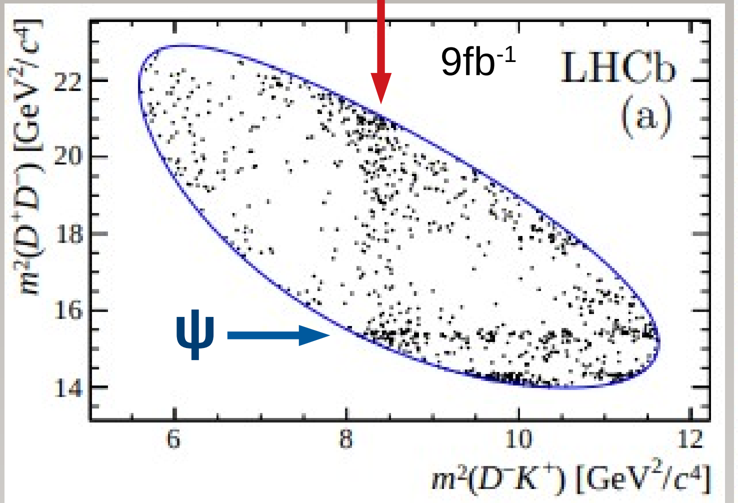
LHCb-FIGURE-2021-001

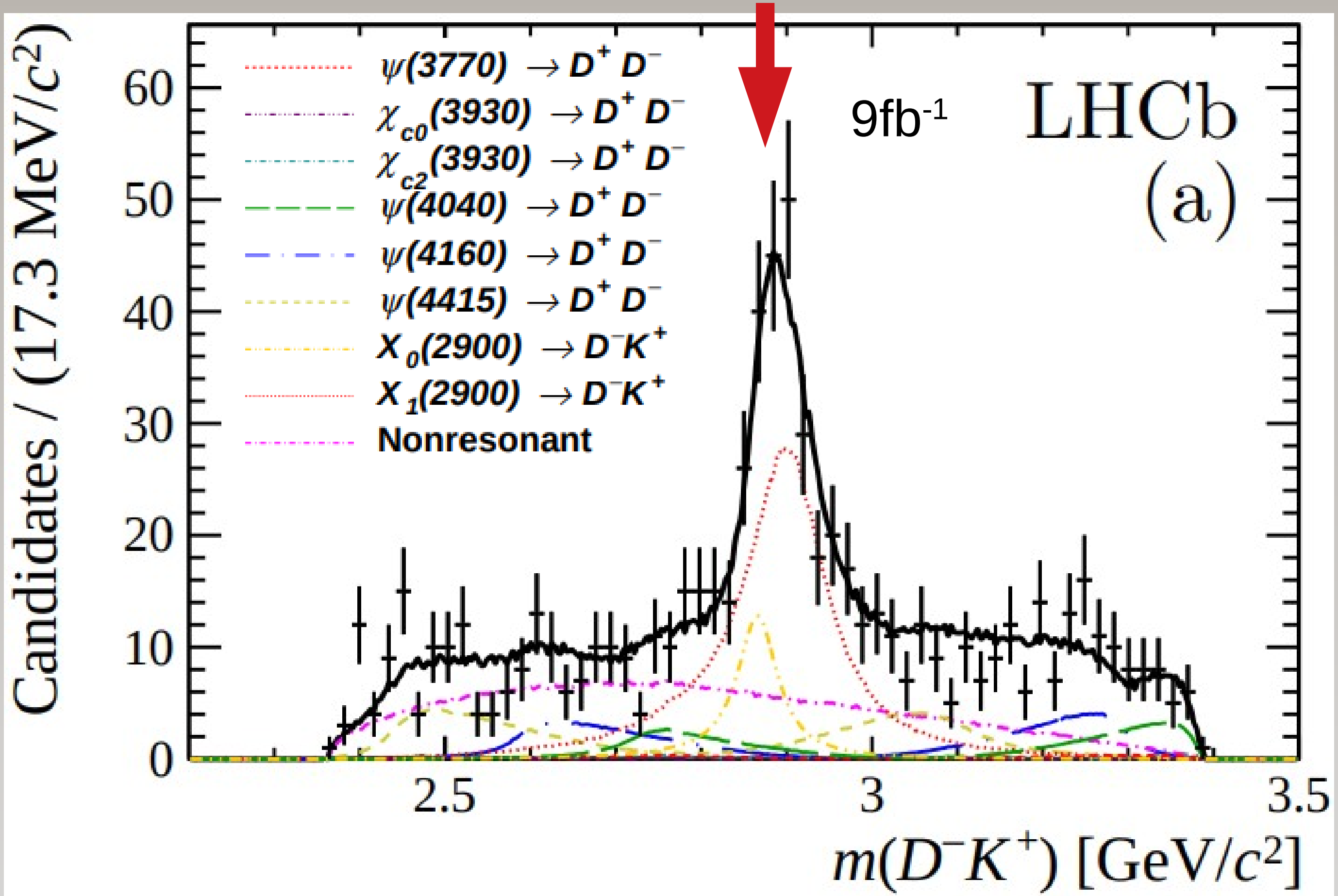
Tetraquark in $B^+ \to D^+ D^- K^+$

- Make full amplitude analysis of $B^+ \to D^+ D^- K^+$ Dalitz plot
- Observe 2 peaks in $D^- K^+$ mass distribution
- Minimal quark content $cud\bar{s}$
- a DK* / D*K molecule?

PRL 125 (2020) 242001

PRD 102 (2020) 112003



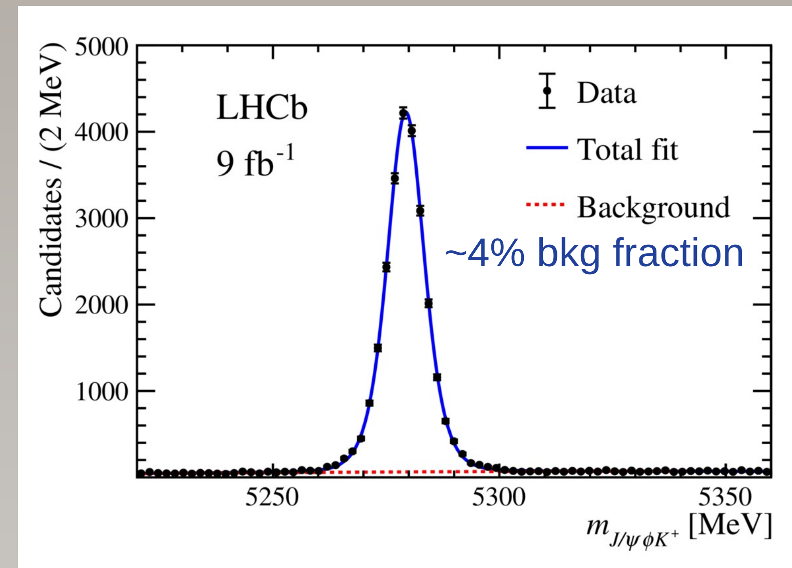


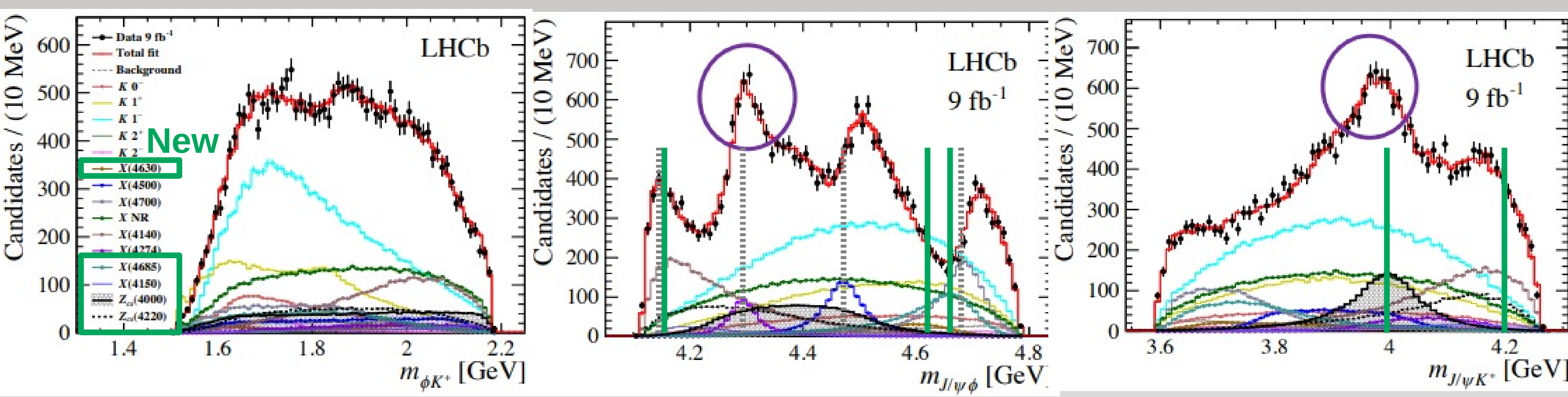
$$X_0(2900): \quad M = 2.866 \pm 0.007 \pm 0.002\,\mathrm{GeV}/c^2, \quad \Gamma = 57 \pm 12 \pm 4\,\mathrm{MeV},$$
$$X_1(2900): \quad M = 2.904 \pm 0.005 \pm 0.001\,\mathrm{GeV}/c^2, \quad \Gamma = 110 \pm 11 \pm 4\,\mathrm{MeV},$$

More exotics in $B^+ \to J/\psi\phi K^+$

LHCb-PAPER-2020-044

- In Run1 analysis four $X \to J/\psi\phi$ states were observed with $S>5\sigma$
  with Run2 get ~6 times larger sample
- Construct 6D amplitude in helicity approach
- Add more states to the Run1 model
  5 K* states + 4X states + $J/\psi\phi$ non-res.
  to get good description:
  + 4 more K* states
  + 2(3) new $X(\to J/\psi\phi)$ states
  + 2 new $Z_{cs}(\to J/\psi K)$ states

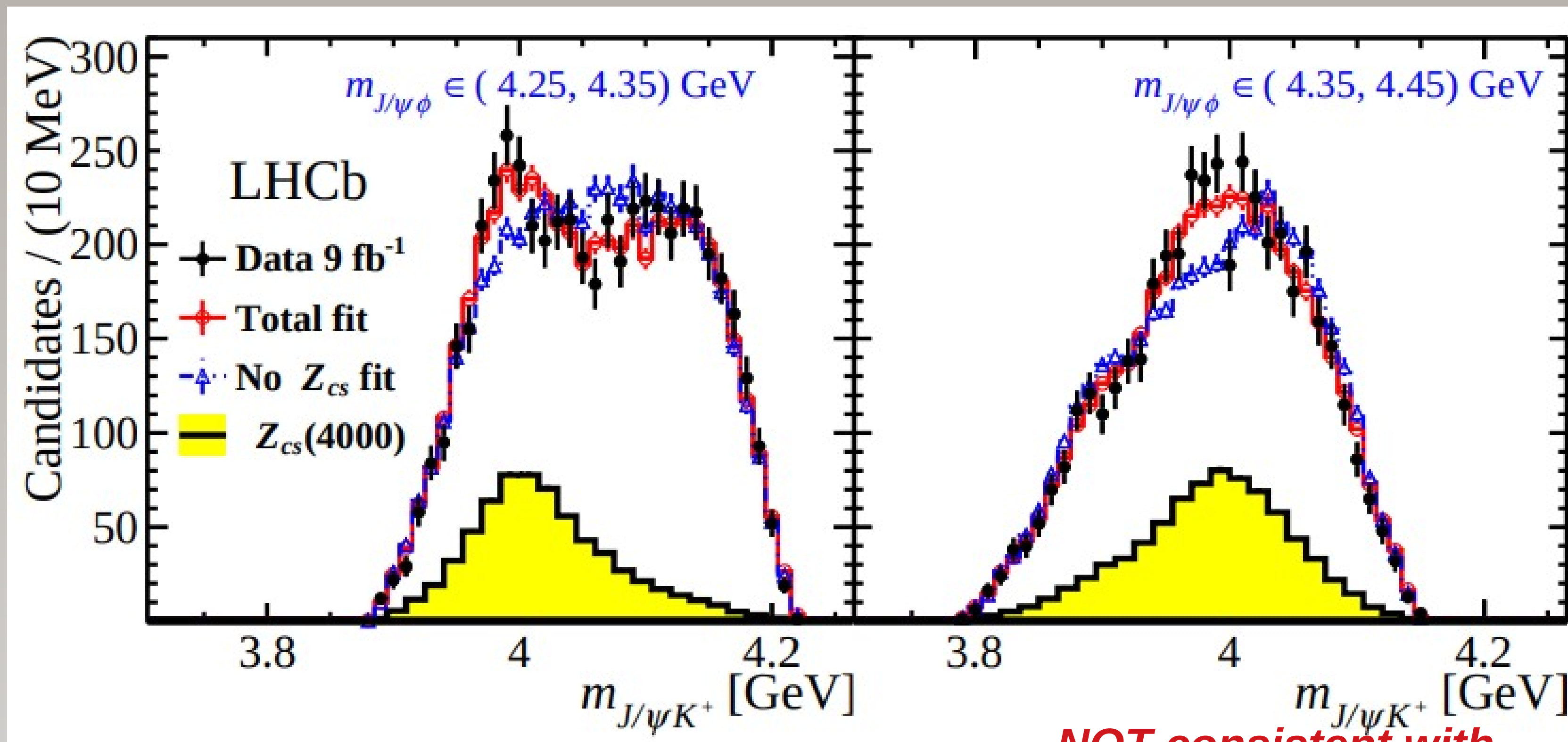




More exotics in $B^+ \to J/\psi\phi K^+$

- Demonstration of effect of adding Z_{cs} states
  - The "narrow" Z_{cs} at 4 GeV is evident

LHCb-PAPER-2020-044



NOT consistent with $Z_{cs}(3985)$ observed by BESIII

Contribution	Significance [$\times\sigma$]	M_0 [MeV]	Γ_0 [MeV]	FF [%]
All $Z_{cs}(1^+)$				$25 \pm 5 ^{+11}_{-12}$
$Z_{cs}(4000)$	15 (16)	$4003 \pm 6 ^{+4}_{-14}$	$131 \pm 15 \pm 26$	$9.4 \pm 2.1 \pm 3.4$
$Z_{cs}(4220)$	5.9 (8.4)	$4216 \pm 24 ^{+43}_{-30}$	$233 \pm 52 ^{+97}_{-73}$	$10 \pm 4 ^{+10}_{-7}$

can't rule out 1^-

More exotics in $B^+ \to J/\psi\phi K^+$ / $\pi^+\pi^-$

- Resulting parameters for X and Z resonances
  - Determine J^P for all states except X(4150), X(4630) and Z_{cs}(4220)

LHCb-PAPER-2020-044

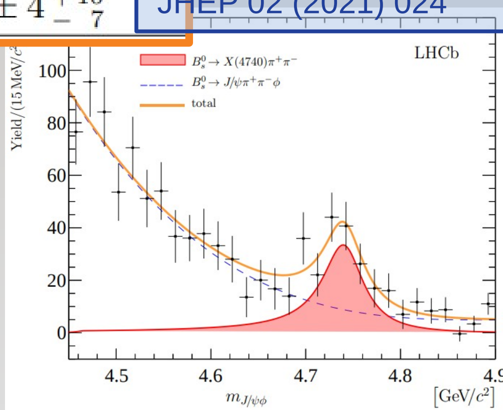
	Contribution	Significance [$\times\sigma$]	M_0 [MeV]	Γ_0 [MeV]	FF [%]
	$X(2^-)$ *can't rule out other J^P*				
	$X(4150)$	4.8 (8.7)	$4146 \pm 18 \pm 33$	$135 \pm 28\,^{+59}_{-30}$	$2.0 \pm 0.5\,^{+0.8}_{-1.0}$
	$X(1^-)$ *can't rule out 2^-*				
New X	$X(4630)$	5.5 (5.7)	$4626 \pm 16\,^{+18}_{-110}$	$174 \pm 27\,^{+134}_{-73}$	$2.6 \pm 0.5\,^{+2.9}_{-1.5}$
	All $X(0^+)$				$20 \pm 5\,^{+14}_{-7}$
Seen in Run1	$X(4500)$	20 (20)	$4474 \pm 3 \pm 3$	$77 \pm 6\,^{+10}_{-8}$	$5.6 \pm 0.7\,^{+2.4}_{-0.6}$
	$X(4700)$	17 (18)	$4694 \pm 4\,^{+16}_{-3}$	$87 \pm 8\,^{+16}_{-6}$	$8.9 \pm 1.2\,^{+4.9}_{-1.4}$
	$NR_{J/\psi\phi}$	4.8 (5.7)			$28 \pm 8\,^{+19}_{-11}$
	All $X(1^+)$				$26 \pm 3\,^{+8}_{-10}$
	$X(4140)$	13 (16)	$4118 \pm 11\,^{+19}_{-36}$	$162 \pm 21\,^{+24}_{-49}$	$17 \pm 3\,^{+19}_{-6}$
	$X(4274)$	18 (18)	$4294 \pm 4\,^{+3}_{-6}$	$53 \pm 5 \pm 5$	$2.8 \pm 0.5\,^{+0.8}_{-0.4}$
	$X(4685)$	15 (15)	$4684 \pm 7\,^{+13}_{-16}$	$126 \pm 15\,^{+37}_{-41}$	$7.2 \pm 1.0\,^{+4.0}_{-2.0}$
	All $Z_{cs}(1^+)$				$25 \pm 5\,^{+11}_{-12}$
New Z_{cs}	$Z_{cs}(4000)$	15 (16)	$4003 \pm 6\,^{+4}_{-14}$	$131 \pm 15 \pm 26$	$9.4 \pm 2.1 \pm 3.4$
	$Z_{cs}(4220)$ *can't rule out 1^-*	5.9 (8.4)	$4216 \pm 24\,^{+43}_{-30}$	$233 \pm 52\,^{+97}_{-73}$	$10 \pm 4\,^{+10}_{-7}$

JHEP 02 (2021) 024

- In $B_s^0 \to J/\psi\phi\pi\pi$ a $X \to J/\psi\phi$ state is seen around 4.74 GeV with S~5.5σ:

$$m_{X(4740)} = 4741 \pm 6 \pm 6 \text{ MeV}/c^2\,,$$
$$\Gamma_{X(4740)} = 53 \pm 15 \pm 11 \text{ MeV}\,,$$

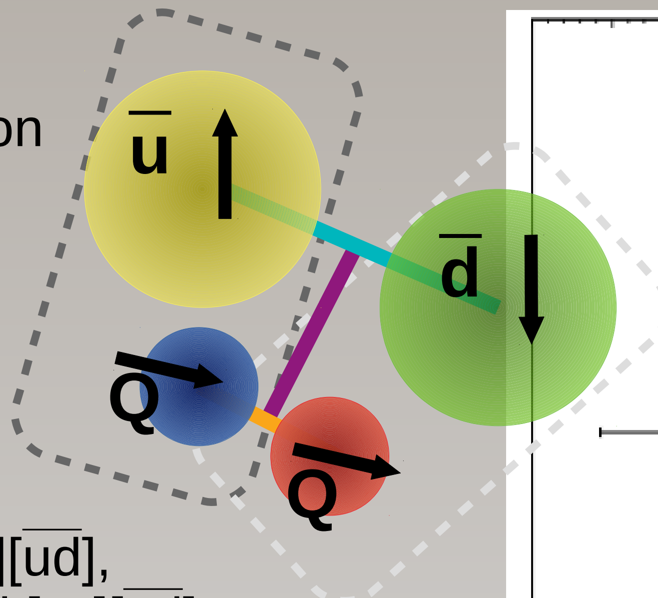
may be consistent with being X(4700) from $B^+ \to J/\psi\phi K$



Doubly charmed tetraquark

- $QQ\bar{q}'\bar{q}''$ states are anticipated for 40 years and are the prime candidates within all other exotic systems to be tightly bound and weakly-decaying

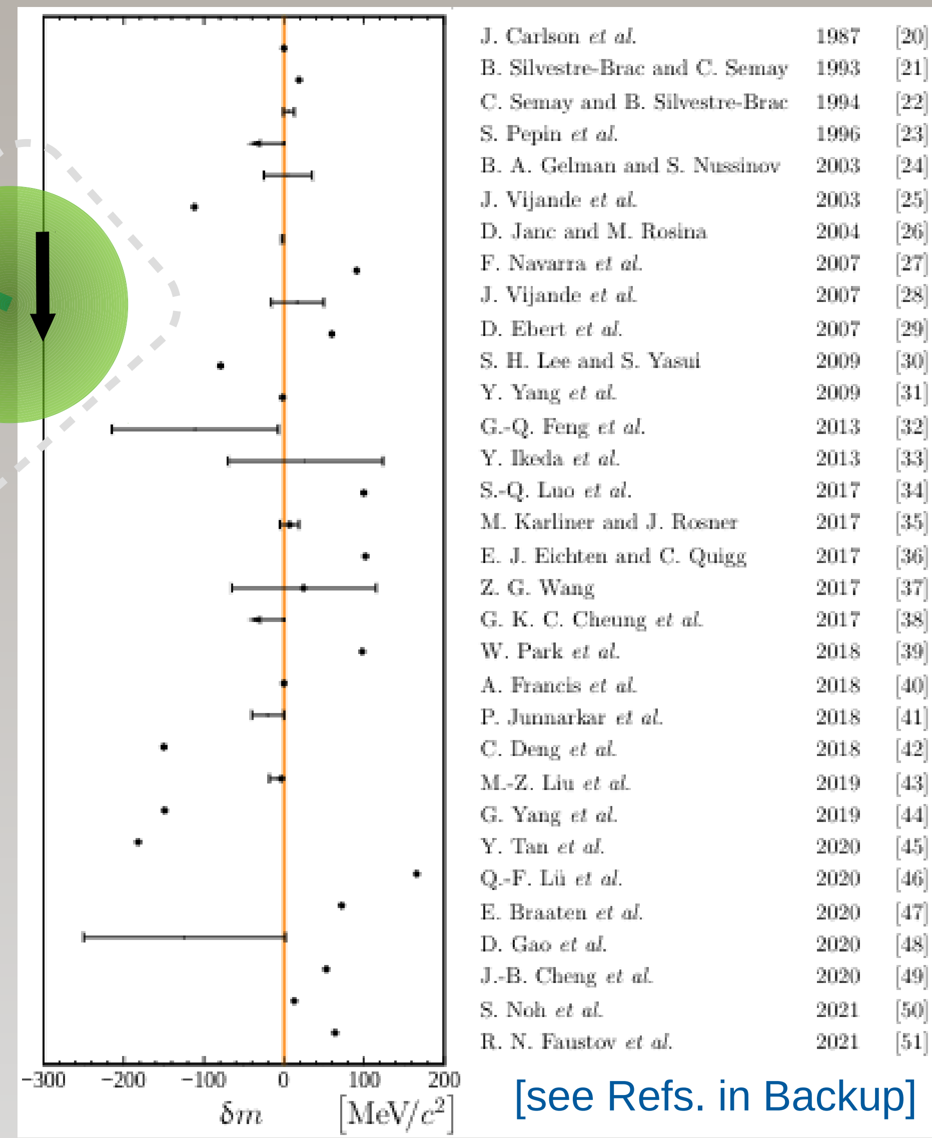
- In $m_Q \rightarrow +\infty$ limit attraction in $[QQ][\bar{u}\bar{d}]$ system should give bound (and thus stable) state



Likely to be true for $[bb][\bar{u}\bar{d}]$, no clear for $[bc][\bar{u}\bar{d}]$ and $[cc][\bar{u}\bar{d}]$

- Predictions for a ground $cc\bar{u}\bar{d}$ state (isoscalar with $J^P=1^+$) vary within ±250MeV wrt to D^0D^{*+} threshold

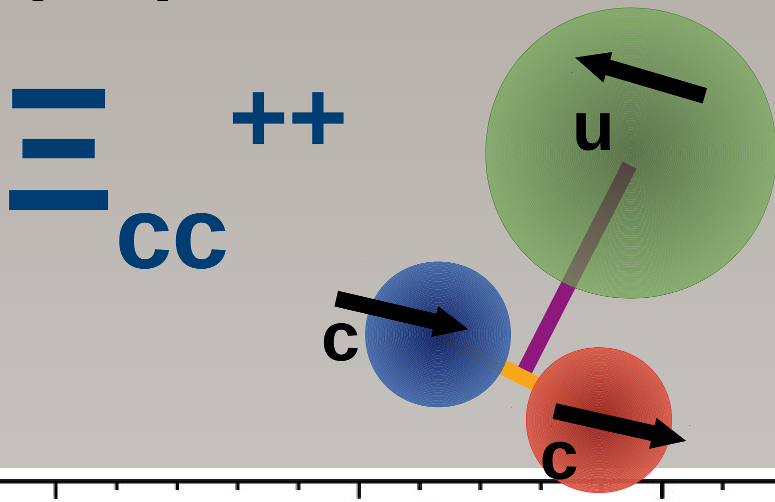
$$\delta m \equiv m_{T_{cc}^+} - (m_{D^{*+}} + m_{D^0})$$

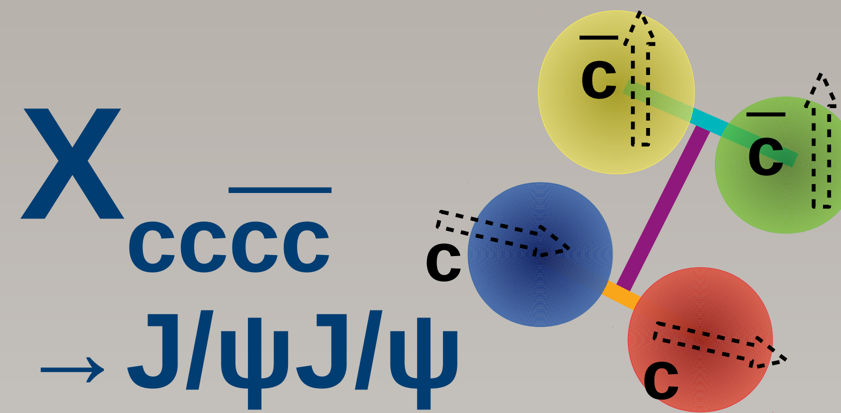


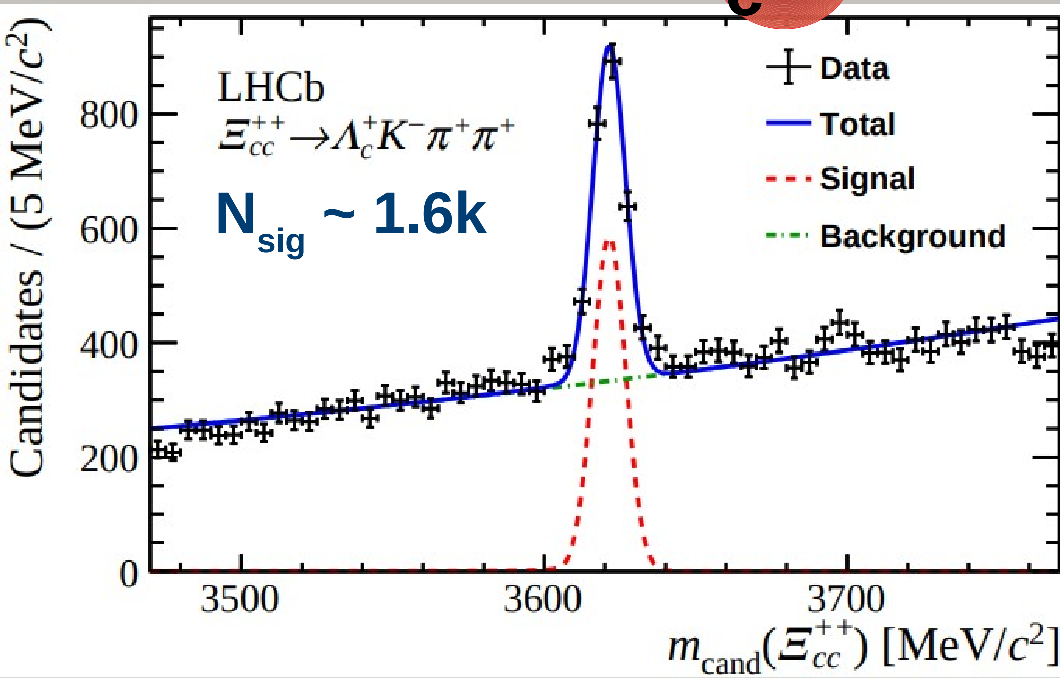
[see Refs. in Backup]

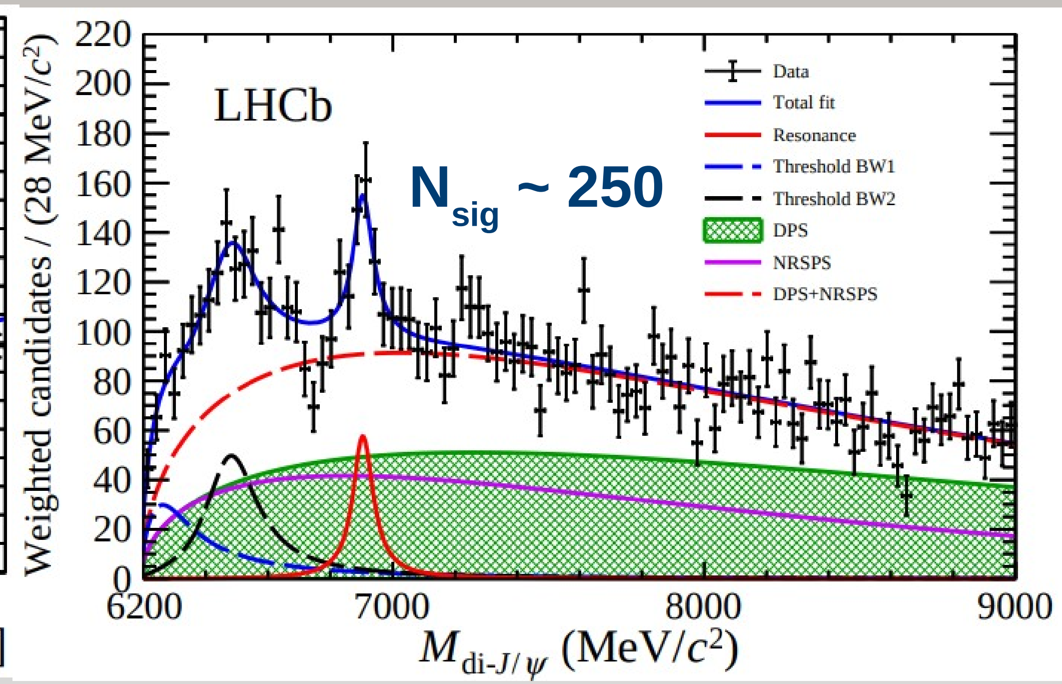
Hadrons with two c-quarks at LHCb

- The observations of Ξ_{cc}^{++} [ccu] and $X[cc\bar{c}\bar{c}] \to J/\psi J/\psi$ indicate that if the $[cc\bar{u}\bar{d}]$ exists it should be accessible at LHCb in $DD^{(*)}$ final states









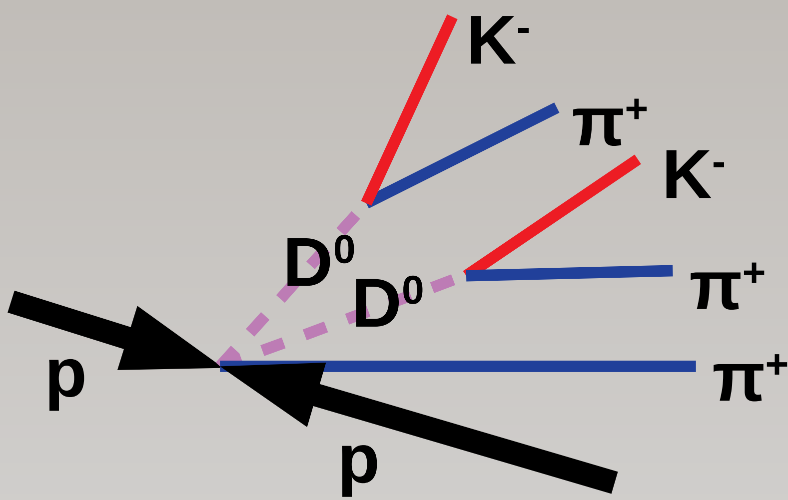
LHCb-PAPER-2019-037

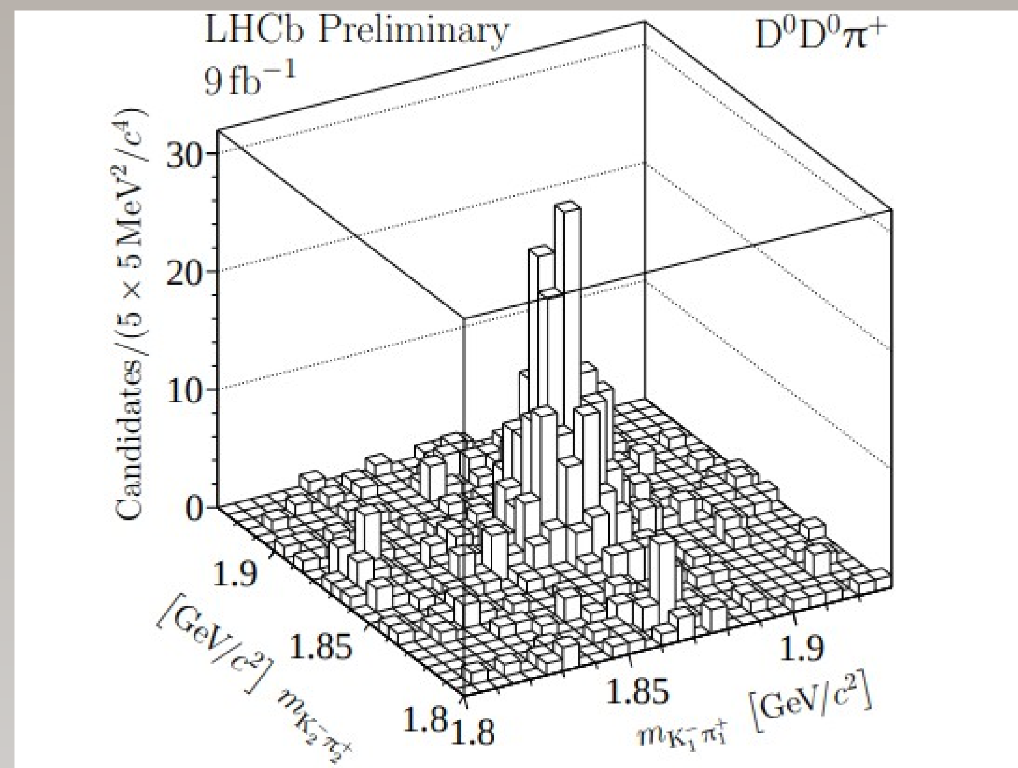
LHCb-PAPER-2020-011

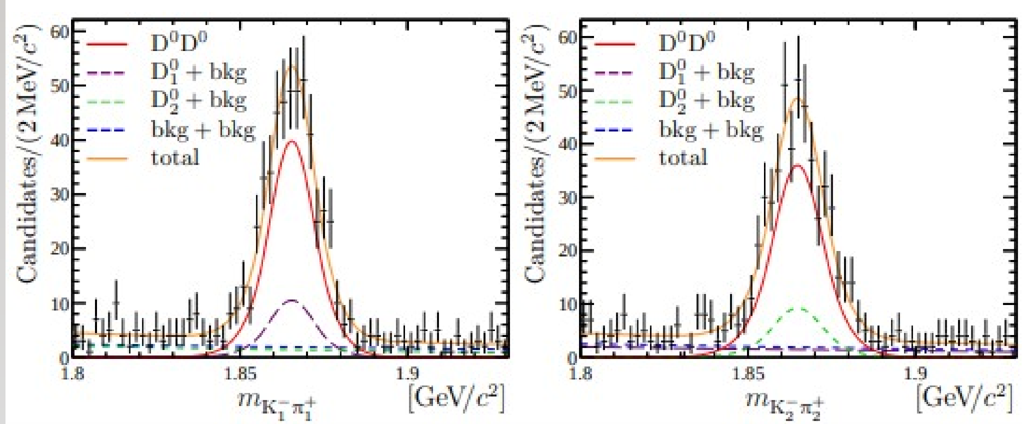
Selection of $D^0D^0\pi^+$

- Select prompt $D^0D^0\pi^+$ candidates via $D^0 \to K^-\pi^+$
- Require non-prompt K^- & π^+ with high p_T
- Require good quality of track, vertexes & particle identification
- Ensure no K/π candidates belong to one track (clones) or duplicates or reflections via mis-ID

LHCb-PAPER-2021-031 in prep.





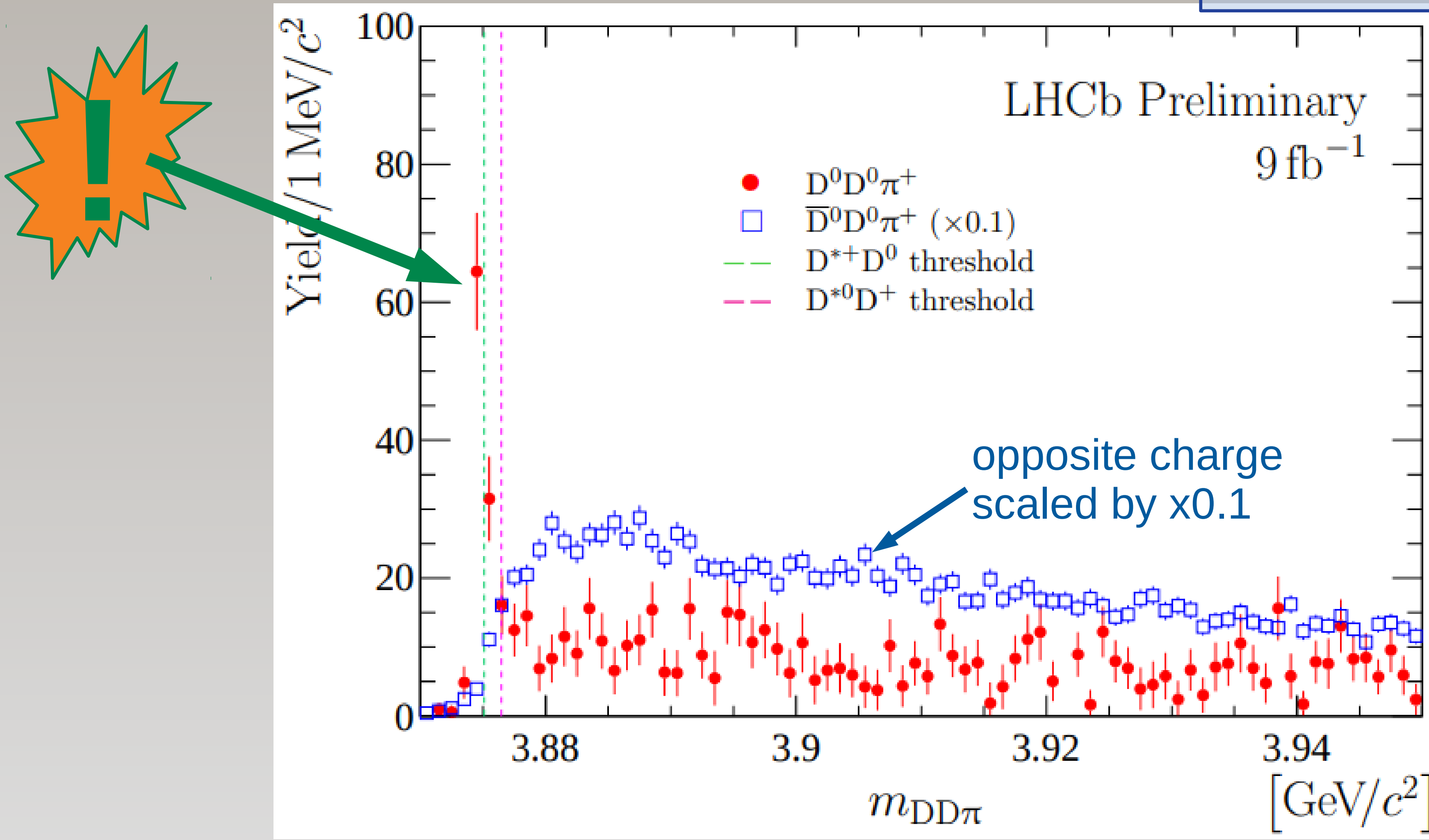


- Subtract fake-D background using 2D fit to $(m_{K\pi}, m_{K\pi})$

Signal

- A narrow peak near DD* threshold is seen
- No peaking structures in sidebands or opposite-sign mode (can't be explained by DCS decay $D^0 \to K^+\pi^-$)
- The structure is present in all different data taking conditions subsamples

LHCb-PAPER-2021-031 in prep.



Fit with Breit-Wigner function

LHCb-PAPER-2021-031 in prep.

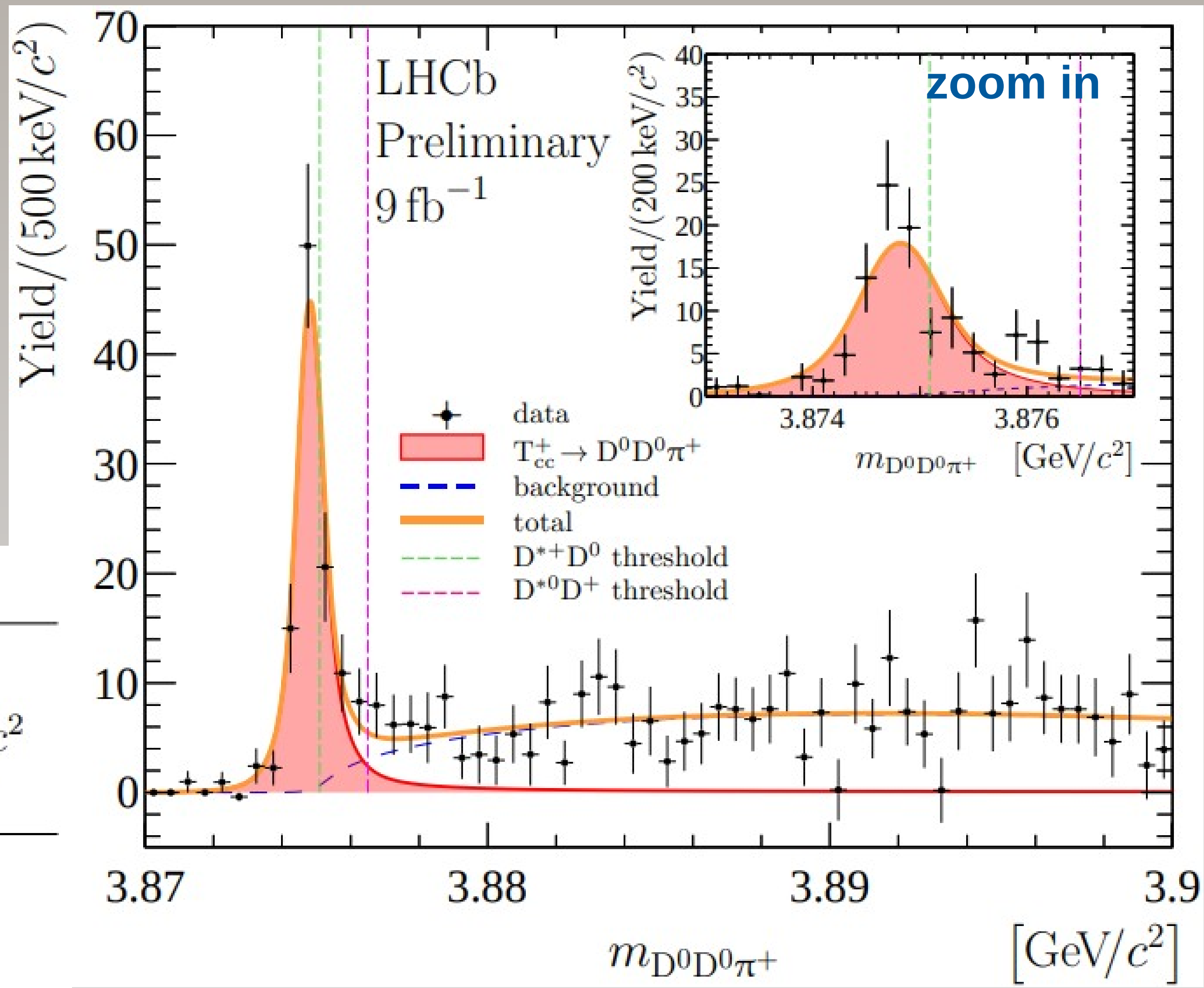
- The distribution is fit with a sum of
  - P-wave relativistic Breit-Wigner
  - $D^{*+}D^0$ phase space x pol_1

  both convolved with resolution of ~400keV

- Found to be below the $D^{*+}D^0$ threshold (with 4.3σ significance for "*below $D^{*+}D^0$*")

- <u>*Preliminary*</u> results:

Parameter	Value
N	117 ± 16
δm_{BW}	-273 ± 61 keV/c^2
Γ_{BW}	410 ± 165 keV
$\mathcal{S}$	21.7 σ
$\mathcal{S}_{\delta m_{\mathrm{BW}}<0}$	4.3 σ

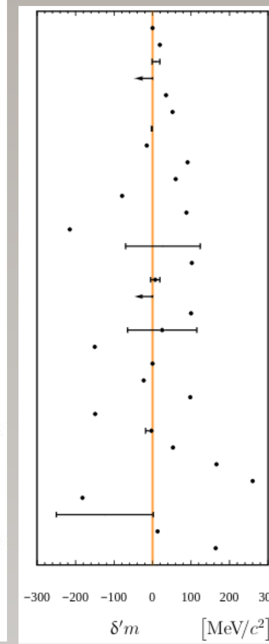


Systematic uncertainties and result

LHCb-PAPER-2021-031 in prep.

- ***Preliminary:***

Source	$\sigma_{\delta m_{\mathrm{BW}}}$ [keV/c^2]	$\sigma_{\Gamma_{\mathrm{BW}}}$ [keV]
Fit model		
Resolution model	2	7
Resolution correction factor	1	30
Background model	3	30
Model parameters	<1	<1
Momentum scale	3	—
Energy loss corrections	1	—
$D^{*+} - D^0$ mass difference	2	—
Total	5	43
J^P quantum numbers	$^{+11}_{-14}$	$^{+18}_{-38}$



$$\delta m_{\mathrm{BW}} = -273 \pm 61 \pm 5\,^{+11}_{-14}\,\mathrm{keV}/c^2,$$
$$\Gamma_{\mathrm{BW}} = 410 \pm 165 \pm 43\,^{+18}_{-38}\,\mathrm{keV},$$

consistent with 1/3 of theory predictions

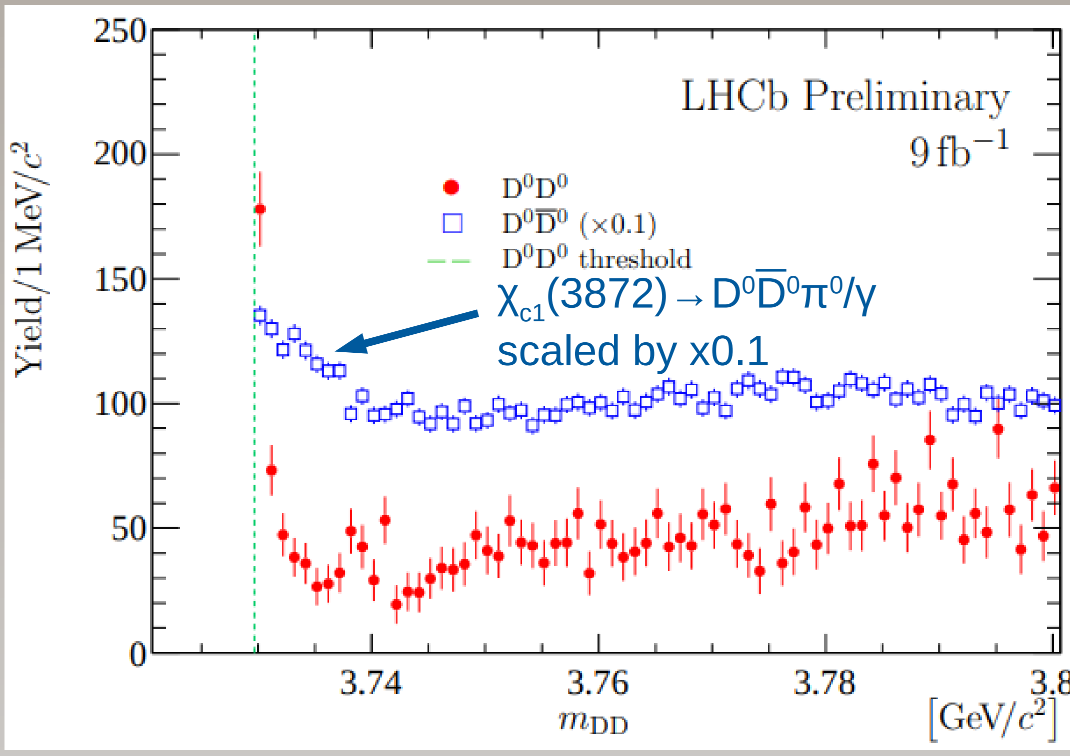
- Best precision on mass wrt corresponding threshold of all exotic hadrons! Even better than for Λ_c^+, Σ_c, Ξ_{cc}^{++} ...

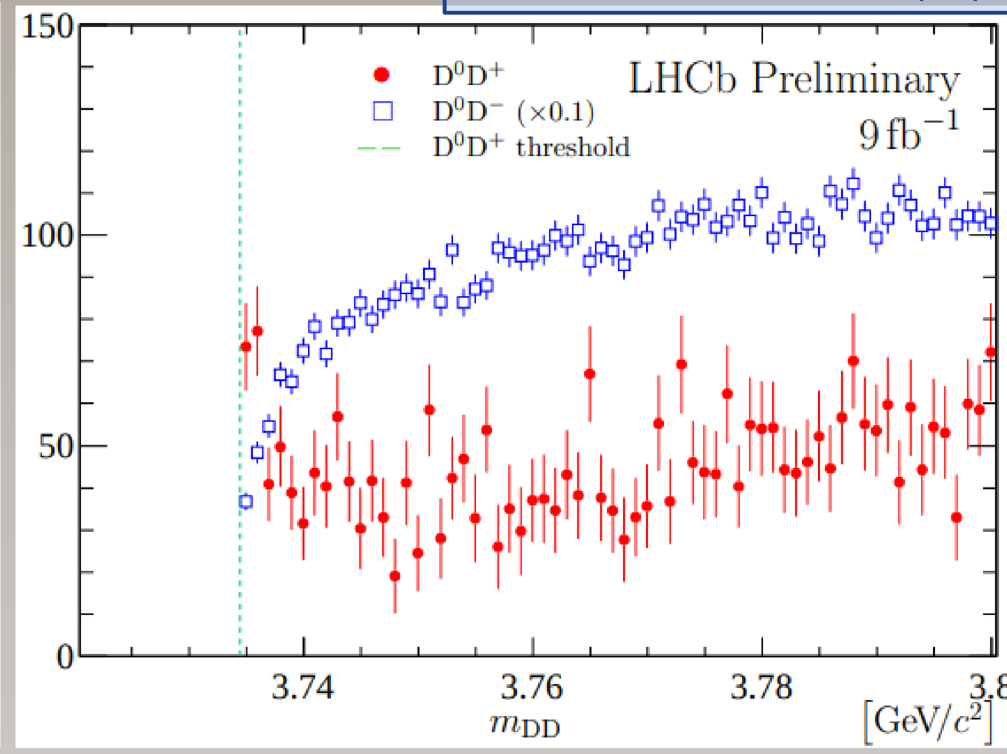
- A fit with dedicated model with adequate treatment of DD* thresholds is coming soon ...

LHCb-PAPER-2021-032 in prep.

D^0D^0 and D^0D^+ mass distributions

LHCb-PAPER-2021-031 in prep.





- Two more stuctures at thresholds are seen:
  - narrow (<1MeV) in D^0D^0 (is it $X \to D^0D^0\pi^+$?)
  - wide (>1MeV) in D^0D^+ (is it $X \to D^0D^+\pi^0/\gamma$?)

  → speaks towards the isoscalar T_{cc}^+ with $J^P=1^+$ interpretation
- See these (and more) studies in details in oncoming LHCb-PAPER-2021-032 in prep.
- Estimate on yields wrt $\chi_{c1}(3872)$: $\dfrac{N(T_{cc}^+ \to D^0D^0\pi^+)}{N(\chi_{c1}(3872) \to D^0\overline{D}^0\pi^0)} \sim 1/20$

Summary

- Observation of $[cu\bar{d}\bar{s}]$ tetraquark in $B^+ \to D^+D^-K^+$
- Observation of new $Z \to J/\psi\varphi$ and $Z \to J/\psi K$ in $B^+ \to J/\psi\varphi K$ (and $B \to J/\psi\varphi\pi\pi$)

PRL 125 (2020) 242001

PRD 102 (2020) 112003

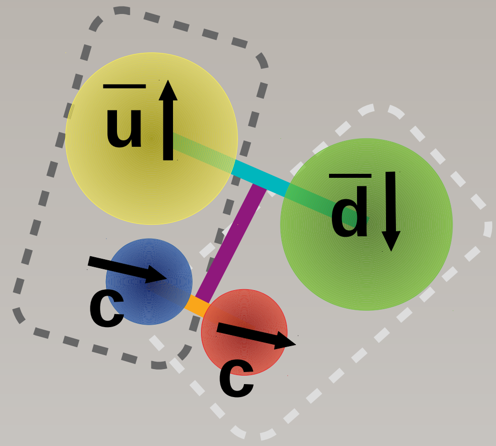
LHCb-PAPER-2020-044

JHEP 02 (2021) 024

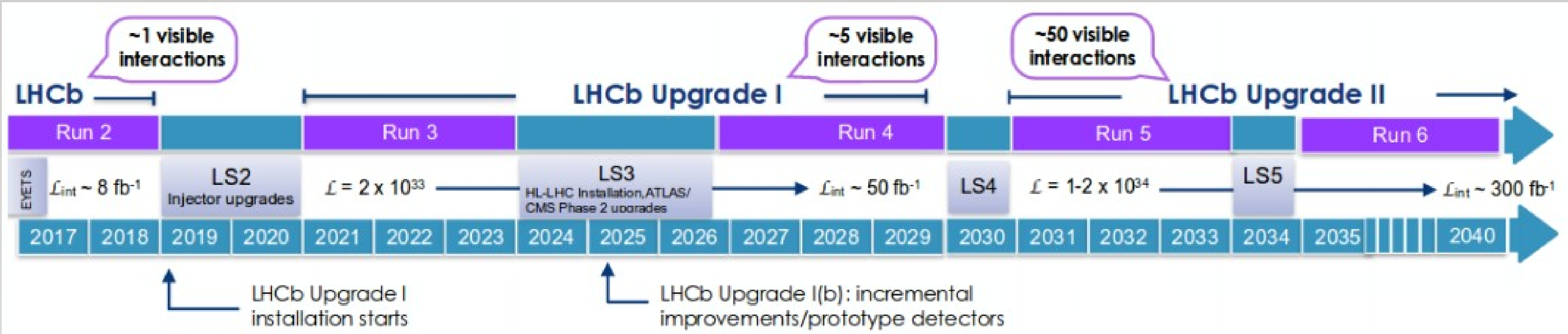
- A novel class of hadrons observed – $[cc\bar{u}\bar{d}]$. consistent with predicted $T_{cc}^{\ +}$ with $J^P=1^+$ near D^0D^{*+} threshold

LHCb-PAPER-2021-031/32, in prep.

→ *new J/ψ-quality input for spectroscopy calculations!*



- Observation of $\Lambda_b^{\ 0} \to \chi_{c1} p \pi^-$ LHCb-PAPER-2021-003
- See new discoveries in pentaquarks in *talk by Jinlin Fu, in 30 min* *[link]*
- LHCb Upgrade is ongoing, will have x5 more statistics by 2030. next portion of interesting results is awaiting



Simon Eidelman 1948 - 2021

Our distinguished colleague, beloved member of LHCb and whole hadron physics community has passed away.

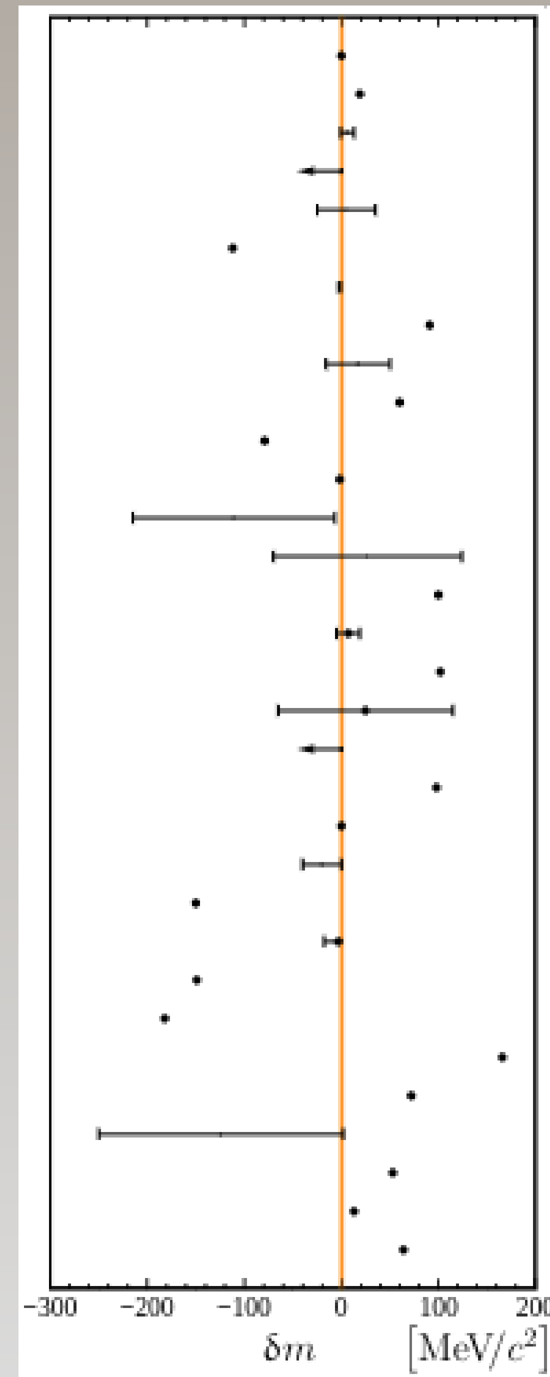
His contribution to the field will have a lasting impact in future generations.

We dedicate the oncoming papers on the observation of the T_{cc}^{+} to his memory.

Backup

Theory predictions

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	$7 \pm 12 \to 1$
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. Lü, 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	$+64$



Refs. for theory predictions

[36] J. Carlson, L. Heller, and J. A. Tjon, *Stability of dimesons*, Phys. Rev. **D37** (1988) 744. 2

[37] B. Silvestre-Brac and C. Semay, *Systematics of $L = 0$ $q^2\bar{q}^2$ systems*, Z. Phys. **C57** (1993) 273. 2

[38] C. Semay and B. Silvestre-Brac, *Diquonia and potential models*, Z. Phys. **C61** (1994) 271. 2

[39] S. Pepin, F. Stancu, M. Genovese, and J. M. Richard, *Tetraquarks with color blind forces in chiral quark models*, Phys. Lett. **B393** (1997) 119, arXiv:hep-ph/9609348. 2

[40] B. A. Gelman and S. Nussinov, *Does a narrow tetraquark $cc\bar{u}\bar{d}$ state exist?*, Phys. Lett. **B551** (2003) 296, arXiv:hep-ph/0209095. 2

[41] J. Vijande, F. Fernandez, A. Valcarce, and B. Silvestre-Brac, *Tetraquarks in a chiral constituent quark model*, Eur. Phys. J. **A19** (2004) 383, arXiv:hep-ph/0310007. 2

[42] D. Janc and M. Rosina, *The $T_{cc} = DD^*$ molecular state*, Few Body Syst. **35** (2004) 175, arXiv:hep-ph/0405208. 2

[43] F. S. Navarra, M. Nielsen, and S. H. Lee, *QCD sum rules study of $QQ - \bar{u}\bar{d}$ mesons*, Phys. Lett. **B649** (2007) 166, arXiv:hep-ph/0703071. 2

[44] J. Vijande, E. Weissman, A. Valcarce, and N. Barnea, *Are there compact heavy four-quark bound states?*, Phys. Rev. **D76** (2007) 094027, arXiv:0710.2516. 2

[45] D. Ebert, R. N. Faustov, V. O. Galkin, and W. Lucha, *Masses of tetraquarks with two heavy quarks in the relativistic quark model*, Phys. Rev. **D76** (2007) 114015, arXiv:0706.3853. 2

[46] S. H. Lee and S. Yasui, *Stable multiquark states with heavy quarks in a diquark model*, Eur. Phys. J. **C64** (2009) 283, arXiv:0901.2977. 2

[47] Y. Yang, C. Deng, J. Ping, and T. Goldman, *ps-wave $QQ\bar{q}\bar{q}$ state in the constituent quark model*, Phys. Rev. **D80** (2009) 114023. 2

[48] G.-Q. Feng, X.-H. Guo, and B.-S. Zou, *$QQ'\bar{u}\bar{d}$ bound state in the Bethe-Salpeter equation approach*, arXiv:1309.7813. 2

[49] Y. Ikeda *et al.*, *Charmed tetraquarks T_{cc} and T_{cs} from dynamical lattice QCD simulations*, Phys. Lett. **B729** (2014) 85, arXiv:1311.6214. 2

[50] S.-Q. Luo *et al.*, *Exotic tetraquark states with the $qq\bar{Q}\bar{Q}$ configuration*, Eur. Phys. J. **C77** (2017) 709, arXiv:1707.01180. 2

[51] M. Karliner and J. L. Rosner, *Discovery of doubly-charmed Ξ_{cc} baryon implies a stable $(bb\bar{u}\bar{d})$ tetraquark*, Phys. Rev. Lett. **119** (2017) 202001, arXiv:1707.07666. 2

[52] E. J. Eichten and C. Quigg, *Heavy-quark symmetry implies stable heavy tetraquark mesons $Q_iQ_j\bar{q}_k\bar{q}_l$*, Phys. Rev. Lett. **119** (2017) 202002, arXiv:1707.09575. 2

[53] Z.-G. Wang, *Analysis of the axialvector doubly heavy tetraquark states with QCD sum rules*, Acta Phys. Polon. **B49** (2018) 1781, arXiv:1708.04545. 2

[54] Hadron Spectrum collaboration, G. K. C. Cheung, C. E. Thomas, J. J. Dudek, and R. G. Edwards, *Tetraquark operators in lattice QCD and exotic flavour states in the charm sector*, JHEP **11** (2017) 033, arXiv:1709.01417. 2

[55] W. Park, S. Noh, and S. H. Lee, *Masses of the doubly heavy tetraquarks in a constituent quark model*, Acta Phys. Polon. **B50** (2019) 1151, arXiv:1809.05257. 2

[56] A. Francis, R. J. Hudspith, R. Lewis, and K. Maltman, *Evidence for charm-bottom tetraquarks and the mass dependence of heavy-light tetraquark states from lattice QCD*, Phys. Rev. **D99** (2019) 054505, arXiv:1810.10550. 2

[57] P. Junnarkar, N. Mathur, and M. Padmanath, *Study of doubly heavy tetraquarks in Lattice QCD*, Phys. Rev. **D99** (2019) 034507, arXiv:1810.12285. 2

[58] C. Deng, H. Chen, and J. Ping, *Systematical investigation on the stability of doubly heavy tetraquark states*, Eur. Phys. J. **A56** (2020) 9, arXiv:1811.06462. 2

[59] M.-Z. Liu *et al.*, *Heavy-quark spin and flavor symmetry partners of the X(3872) revisited: What can we learn from the one boson exchange model?*, Phys. Rev. **D99** (2019) 094018, arXiv:1902.03044. 2

[60] G. Yang, J. Ping, and J. Segovia, *Doubly-heavy tetraquarks*, Phys. Rev. **D101** (2020) 014001, arXiv:1911.00215. 2

[61] Y. Tan, W. Lu, and J. Ping, *$QQ\bar{q}\bar{q}$ in a chiral constituent quark model*, Eur. Phys. J. Plus **135** (2020) 716, arXiv:2004.02106. 2

[62] Q.-F. Lü, D.-Y. Chen, and Y.-B. Dong, *Masses of doubly heavy tetraquarks $T_{QQ'}$ in a relativized quark model*, Phys. Rev. **D102** (2020) 034012, arXiv:2006.08087. 2

[63] E. Braaten, L.-P. He, and A. Mohapatra, *Masses of doubly heavy tetraquarks with error bars*, Phys. Rev. D **103** (2021) 016001, arXiv:2006.08650. 2

[64] D. Gao *et al.*, *Masses of doubly heavy tetraquark states with isospin $= \frac{1}{2}$ and 1 and spin-parity $1^{+\pm}$*, arXiv:2007.15213. 2

[65] J.-B. Cheng *et al.*, *Double-heavy tetraquark states with heavy diquark-antiquark symmetry*, arXiv:2008.00737. 2

[66] S. Noh, W. Park, and S. H. Lee, *The doubly-heavy tetraquarks $(qq'\bar{Q}\bar{Q}')$ in a constituent quark model with a complete set of harmonic oscillator bases*, arXiv:2102.09614. 2

[67] R. N. Faustov, V. O. Galkin, and E. M. Savchenko, *Heavy tetraquarks in the relativistic quark model*, Universe **7** (2021) 94, arXiv:2103.01763. 2

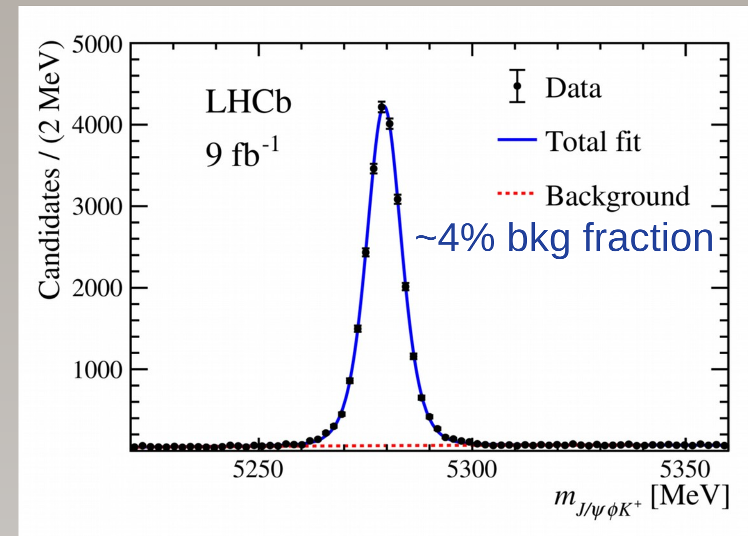
New exotics in $B^+ \to J/\psi\phi K^+$

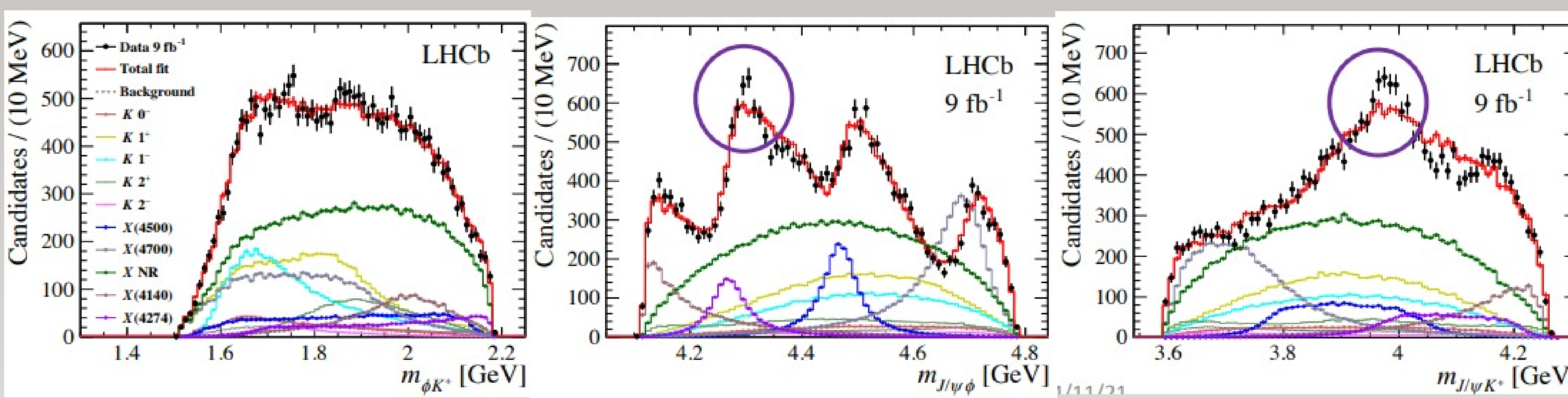
- In Run1 analysis four $X \to J/\psi\phi$ states were observed with S>5σ
- With Run2 get ~6 times larger sample

- Construct 6D amplitude in helicity approach
  Model resonances as Breit-Wigner,
  K-matrix or Flatte for systematic studies

- Firstly try old Run1 model (5K* + 4X + XNR)
  Clear discrepancies are observed,
  model needs to be improved

LHCb-PAPER-2020-044





New exotics in $B^+ \to J/\psi\phi K^+$

LHCb-PAPER-2020-044

- Model improvements
  - Include tails of K* resonances at ~1.4 GeV
  - Add more $X \to J/\psi\phi$ and $Z_{cs} \to J/\psi K^+$ states

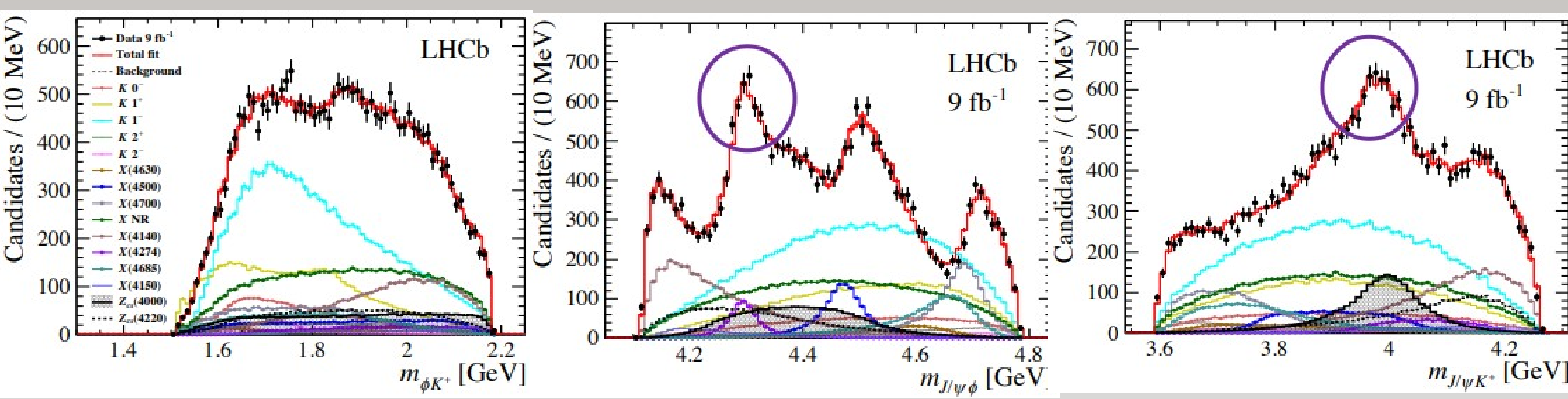
    - firstly with $J^P=1^+$ (largest improvement),

    - later with other quantum numbers

  → found a need for 3 more X states and 2 Z_{cs} states with >5σ significance (except for one X)

  - new default model: 9K* + 7X + 1X(NR) + 2Z_{cs}

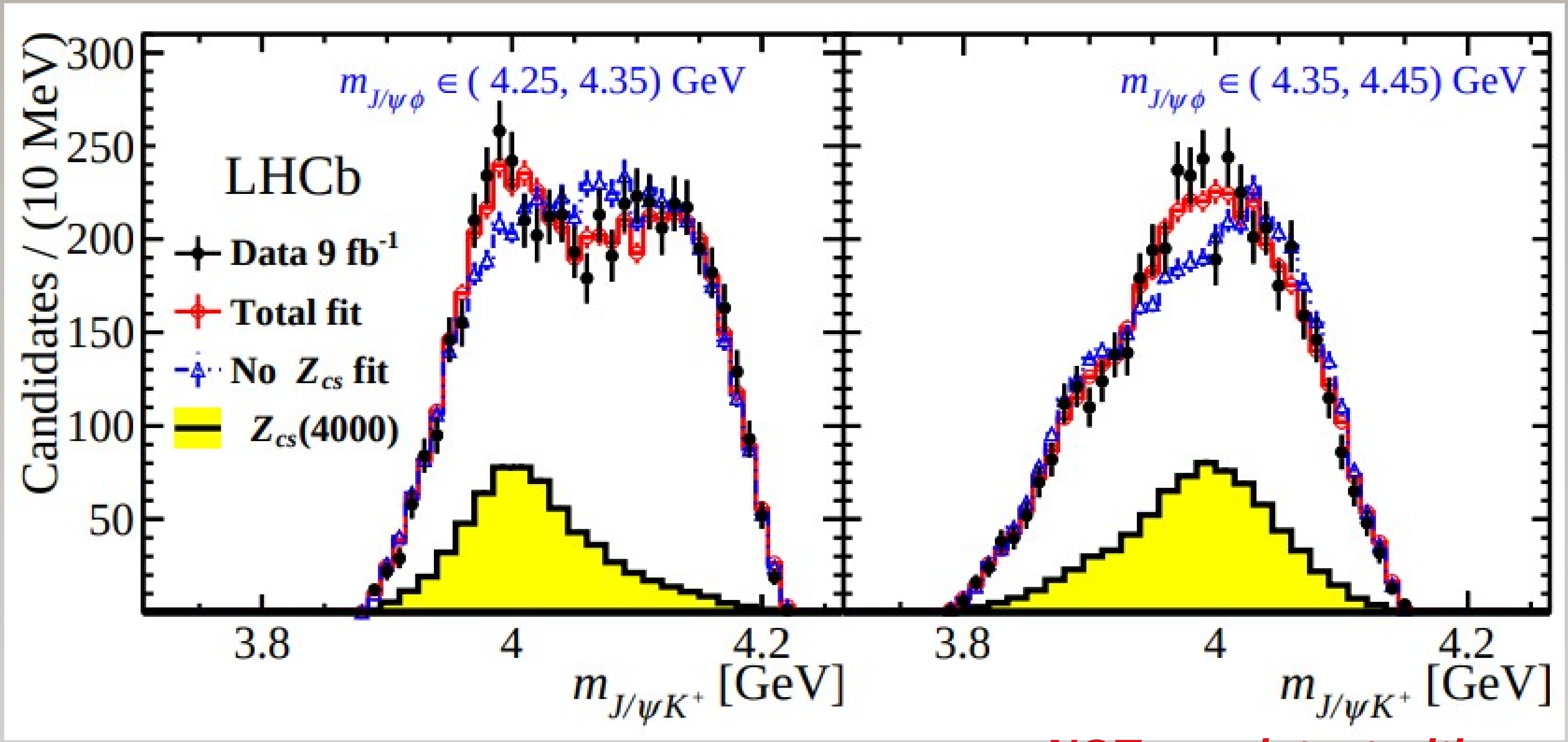
- Get good data description



New exotics in $B^+ \to J/\psi\phi K^+$

LHCb-PAPER-2020-044

- Demonstration of effect of adding Z_{cs} states
  - The “narrow” Z_{cs} at 4 GeV is evident



NOT consistent with $Z_{cs}(3985)$ observed by BESIII

New exotics in $B^+ \rightarrow J/\psi\phi K^+$

LHCb-PAPER-2020-044

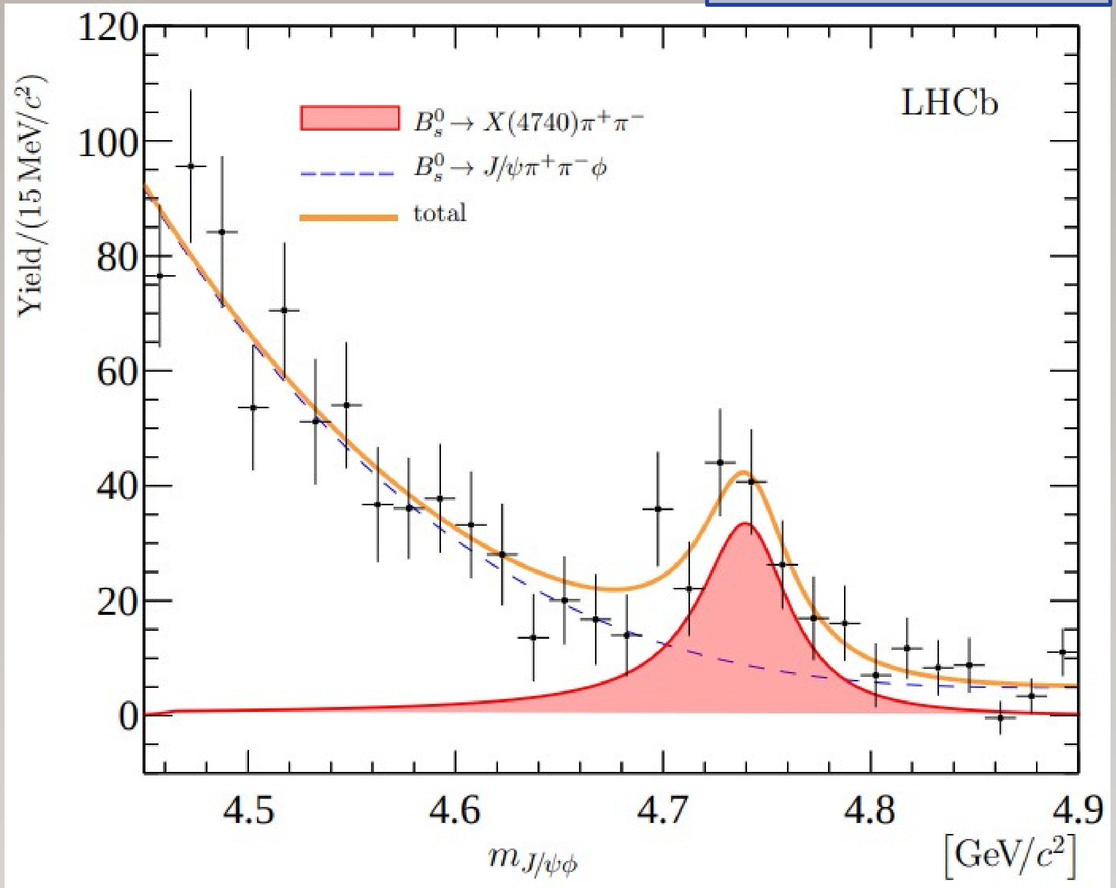
- Resulting parameters for X and Z resonances
  - Determine J^P for all states except X(4150), X(4630) and Z_{cs}(4220)

	Contribution	Significance $[\times\sigma]$	M_0 [MeV]	Γ_0 [MeV]	FF [%]
	$X(2^-)$ *can't rule out other J^P*				
	$X(4150)$	4.8 (8.7)	$4146 \pm 18 \pm 33$	$135 \pm 28\,^{+59}_{-30}$	$2.0 \pm 0.5\,^{+0.8}_{-1.0}$
	$X(1^-)$ *can't rule out 2^-*				
New X	$X(4630)$	5.5 (5.7)	$4626 \pm 16\,^{+18}_{-110}$	$174 \pm 27\,^{+134}_{-73}$	$2.6 \pm 0.5\,^{+2.9}_{-1.5}$
	All $X(0^+)$				$20 \pm 5\,^{+14}_{-7}$
Seen in Run1	$X(4500)$	20 (20)	$4474 \pm 3 \pm 3$	$77 \pm 6\,^{+10}_{-8}$	$5.6 \pm 0.7\,^{+2.4}_{-0.6}$
Seen in Run1	$X(4700)$	17 (18)	$4694 \pm 4\,^{+16}_{-3}$	$87 \pm 8\,^{+16}_{-6}$	$8.9 \pm 1.2\,^{+4.9}_{-1.4}$
	$\mathrm{NR}_{J/\psi\phi}$	4.8 (5.7)			$28 \pm 8\,^{+19}_{-11}$
	All $X(1^+)$				$26 \pm 3\,^{+8}_{-10}$
	$X(4140)$	13 (16)	$4118 \pm 11\,^{+19}_{-36}$	$162 \pm 21\,^{+24}_{-49}$	$17 \pm 3\,^{+19}_{-6}$
	$X(4274)$	18 (18)	$4294 \pm 4\,^{+3}_{-6}$	$53 \pm 5 \pm 5$	$2.8 \pm 0.5\,^{+0.8}_{-0.4}$
	$X(4685)$	15 (15)	$4684 \pm 7\,^{+13}_{-16}$	$126 \pm 15\,^{+37}_{-41}$	$7.2 \pm 1.0\,^{+4.0}_{-2.0}$
	All $Z_{cs}(1^+)$				$25 \pm 5\,^{+11}_{-12}$
New Z_{cs}	$Z_{cs}(4000)$	15 (16)	$4003 \pm 6\,^{+4}_{-14}$	$131 \pm 15 \pm 26$	$9.4 \pm 2.1 \pm 3.4$
New Z_{cs}	$Z_{cs}(4220)$ *can't rule out 1^-*	5.9 (8.4)	$4216 \pm 24\,^{+43}_{-30}$	$233 \pm 52\,^{+97}_{-73}$	$10 \pm 4\,^{+10}_{-7}$

One more X → J/ψφ state

- In $B_s^0 \to J/\psi\phi\pi\pi$ a $X \to J/\psi\phi$ state is seen around 4.74 GeV with S~5.5σ

LHCb-PAPER-2020-035



- Parameters from 1D fit

$$m_{X(4740)} = 4741 \pm 6 \pm 6 \text{ MeV}/c^2 ,$$
$$\Gamma_{X(4740)} = 53 \pm 15 \pm 11 \text{ MeV} ,$$

Consistent with being X(4700) from $B^+ \to J/\psi\phi K$

- Also many results for BR's of $J/\psi K^{*0}K^{*0}$, $\psi(2S)K^+K^-$, X(3872)K+K-… modes