第5届LHCb前沿物理研讨会
2025年4月25-28日

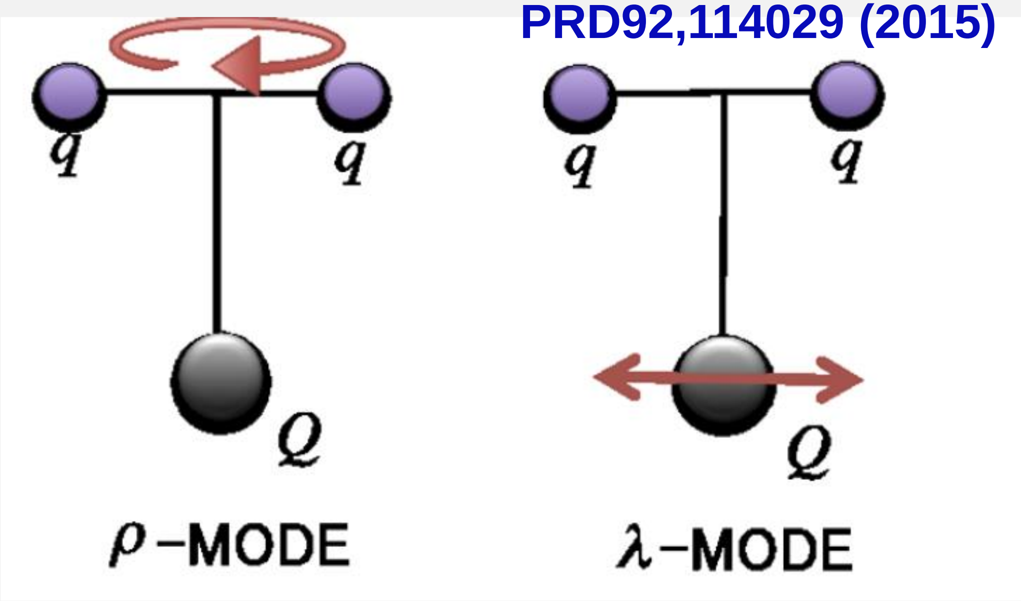
Charmed Baryon

Xian-Hui Zhong (钟显辉)

Hunan Normal University

The simple picture

PRD92,114029 (2015)



Two light quarks: Permutation symmetry

No genuine diquark structure!!! A complex three body problem.

Classification (flavor)

味道6重态（对称）

$$\phi_{\mathbf{6}}^{c}=\begin{cases} uuc & \text{for } \Sigma_c^{++},\\ \frac{1}{\sqrt{2}}(ud+du)c & \text{for } \Sigma_c^{+},\\ ddc & \text{for } \Sigma_c^{0},\\ \frac{1}{\sqrt{2}}(us+su)c & \text{for } \Xi_c^{\prime +},\\ \frac{1}{\sqrt{2}}(ds+sd)c & \text{for } \Xi_c^{\prime 0},\\ ssc & \text{for } \Omega_c^{0}; \end{cases}$$

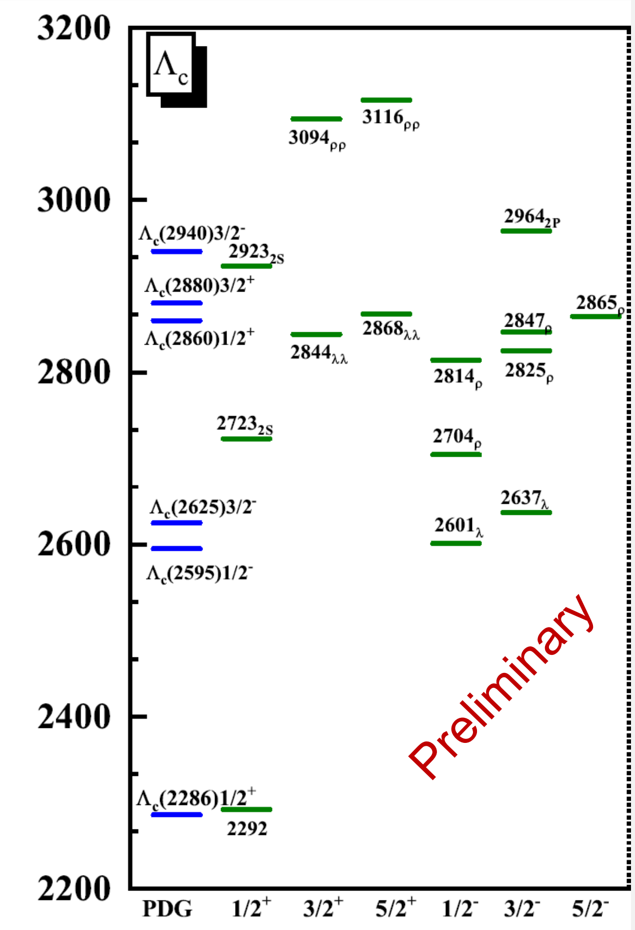
味道反3重态（反对称）

$$\phi_{\bar{\mathbf{3}}}^{c}=\begin{cases} \frac{1}{\sqrt{2}}(ud-du)c & \text{for } \Lambda_c^{+},\\ \frac{1}{\sqrt{2}}(us-su)c & \text{for } \Xi_c^{+},\\ \frac{1}{\sqrt{2}}(ds-sd)c & \text{for } \Xi_c^{0}; \end{cases}$$

Part I
Antisymmetric antitriplet

$\underline{3}_F$ states

Λ_c states



State	Λ_c RQM [21]	NQM [27]	NQM [33]	PDG [24]
$1^2S\frac{1}{2}^+$	2286	2285	2286	2286
$1^2P_\lambda\frac{1}{2}^-$	2598	2628	2614	2592
$1^2P_\lambda\frac{3}{2}^-$	2627	2630	2639	2628
$1^2D_{\lambda\lambda}\frac{3}{2}^+$	2874	2920	2843	2860?
$1^2D_{\lambda\lambda}\frac{5}{2}^+$	2880	2922	2851	2880?

How to establish the high-lying states?

YX Yao, KL Wang, XH, PRD98,076015(2018)

Evidence of D-wave Λ_c states

$\boxed{\Lambda_c(2860)^+}$

$I(J^P) = 0(\frac{3}{2}^+)$

M =2856 MeV,
Γ =68 MeV

Only seen in D^0p channel

JHEP 1705 030 R. Aaij *et al.*

PDG，PRD110, 030001(2004)

$\boxed{\Lambda_c(2880)^+}$

$I(J^P) = 0(\frac{5}{2}^+)$

M =2882 MeV,
Γ =5.6 MeV

Decay modes:

Γ_1	$\Lambda_c^+ \pi^+ \pi^-$
Γ_2	$\Sigma_c(2455)^{0,++} \pi^\pm$
Γ_3	$\Sigma_c(2520)^{0,++} \pi^\pm$
Γ_4	$p D^0$

Our explaination

Decay mode	$\lvert\Lambda_c\,^2D_{\lambda\lambda}\frac{3}{2}^+\rangle(2856)$ Γ_i (MeV)	$\lvert\Lambda_c\,^2D_{\lambda\lambda}\frac{5}{2}^+\rangle(2881)$ Γ_i (MeV)
$\Sigma_c\pi$	$4.57^{+1.09}_{-1.20}$	$1.33^{-0.35}_{+0.50}$
$\Sigma_c^*\pi$	$0.95^{-0.03}_{+0.09}$	$4.38^{+0.67}_{-0.74}$
Sum	$5.52^{+1.06}_{-1.11}$	$5.71^{+0.32}_{-0.24}$

- Λ_c (2860) and Λ_c (2880) most likely corresponds to the two D-wave Λ_c states.
- To confirm the Λ_c (2860), look for the $\Sigma_c\pi$ mode.
- M[Λ_c (2880)5/2$^+$)] > M[Λ_c (2860)3/2$^+$]

YX Yao, KL Wang, XH, PRD98,076015(2018)

Higher Λ_c state, 2940

$\boxed{\Lambda_c(2940)^+}$ $I(J^P) = 0(\frac{3}{2}^-)$ Status: ∗∗∗

A narrow peak seen in pD^0 and in $\Lambda_c^+\pi^+\pi^-$. It is not seen in pD^+, and therefore it is a Λ_c^+ and not a Σ_c. $J^P = 3/2^-$ is favored, but not certain.

TABLE VIII: The partial decay widths of $\Lambda_c(2940)^+$ assigned as the two $2P$-wave λ-mode Λ_c states $\Lambda_{c1}|J^P = 1/2^-, 1\rangle_\lambda$ and $\Lambda_{c1}|J^P = 3/2^-, 1\rangle_\lambda$, respectively.

Decay width	$\Lambda_{c1}\|J^P = 1/2^-, 1\rangle_\lambda$	$\Lambda_{c1}\|J^P = 3/2^-, 1\rangle_\lambda$
	M=2940	$\Lambda_c(2940)^+$
$\Gamma[\Sigma_c\pi]$	0.68	2.28
$\Gamma[\Sigma_c^*\pi]$	3.18	1.61
$\Gamma[pD^0]$	5.72	10.21
$\Gamma[nD^+]$	6.89	9.55
Γ_{Total}	16.47	23.65
Expt.	20^{+6}_{-5}	

Preliminary

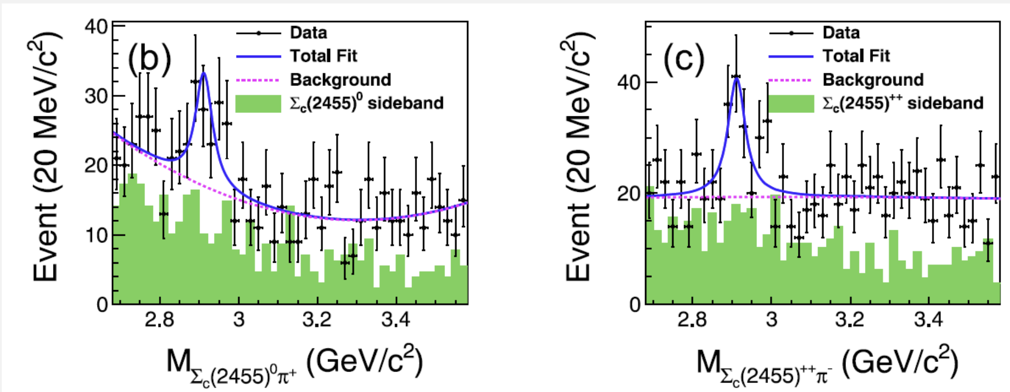
Λ_c (2940) may be the 2P state with JP=3/2-.

Li-Ye Xiao and XH Zhong, to be published

$\Lambda_c(2910)^+$

$I(J^P) = ?(?^?)$ Status: $*$

M=2913.8(9.4) MeV, Γ=51.8(38.8) MeV



Y. B. Li, C.P. Shen et al (Belle Collab.), PRL130,031901

TABLE VIII: The partial decay widths of $\Lambda_c(2940)^+$ assigned as the two $2P$-wave λ-mode Λ_c states $\Lambda_{c1}|J^P = 1/2^-, 1\rangle_\lambda$ and $\Lambda_{c1}|J^P = 3/2^-, 1\rangle_\lambda$, respectively.

Preliminary

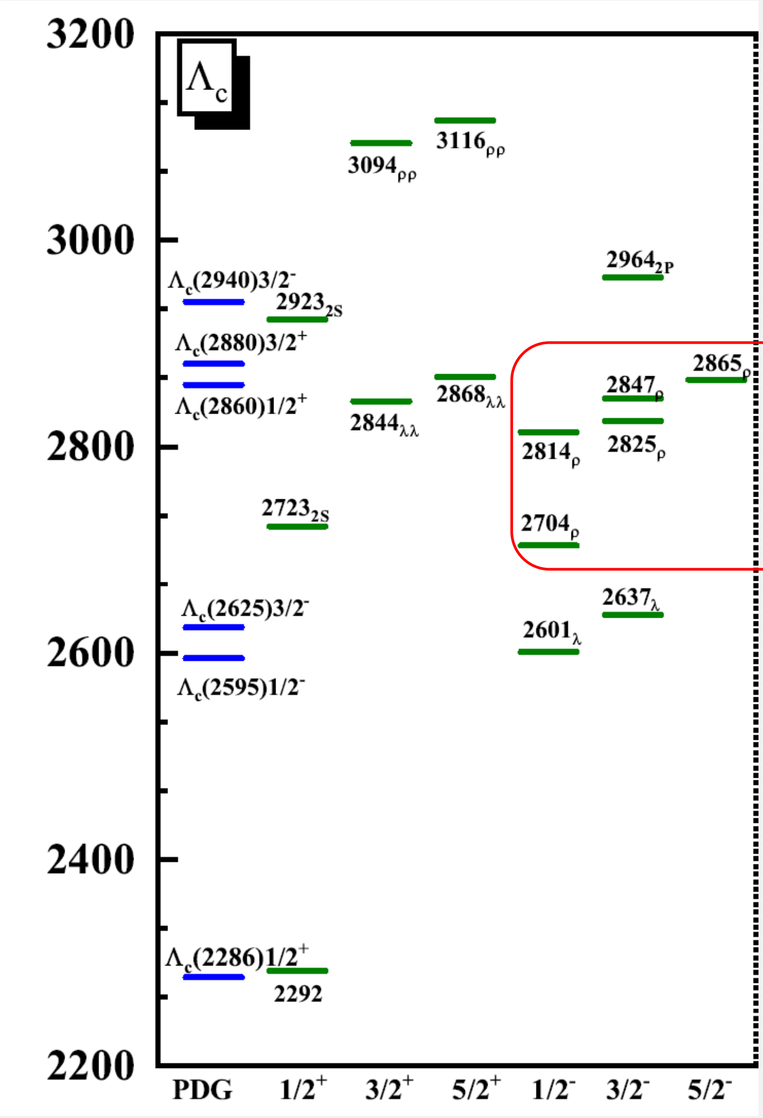
Decay width	$\Lambda_{c1}\lvert J^P = 1/2^-, 1\rangle_\lambda$	$\Lambda_{c1}\lvert J^P = 3/2^-, 1\rangle_\lambda$
	M=2940	$\Lambda_c(2940)^+$
$\Gamma[\Sigma_c\pi]$	0.68	2.28
$\Gamma[\Sigma_c^*\pi]$	3.18	1.61
$\Gamma[pD^0]$	5.72	10.21
$\Gamma[nD^+]$	6.89	9.55
Γ_{Total}	16.47	23.65
Expt.	20^{+6}_{-5}	

Li-Ye Xiao and XH Zhong, to be published

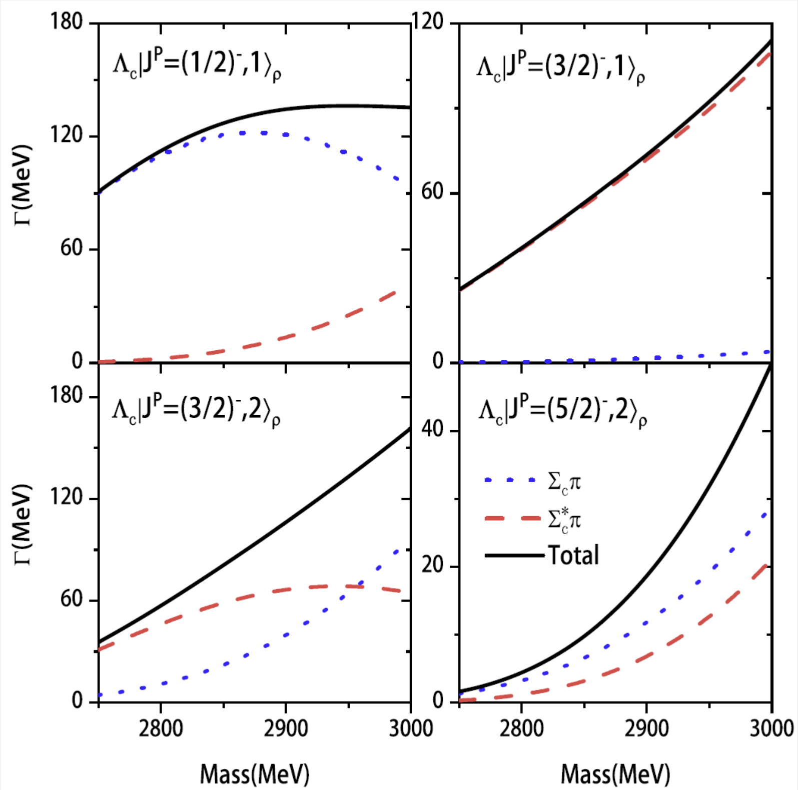
If Λ_c (2910) assigned as a 2P state, it should be a narrow state.

More studies are needed!

Can we find rho mode 1P states @2.7-2.9 GeV?



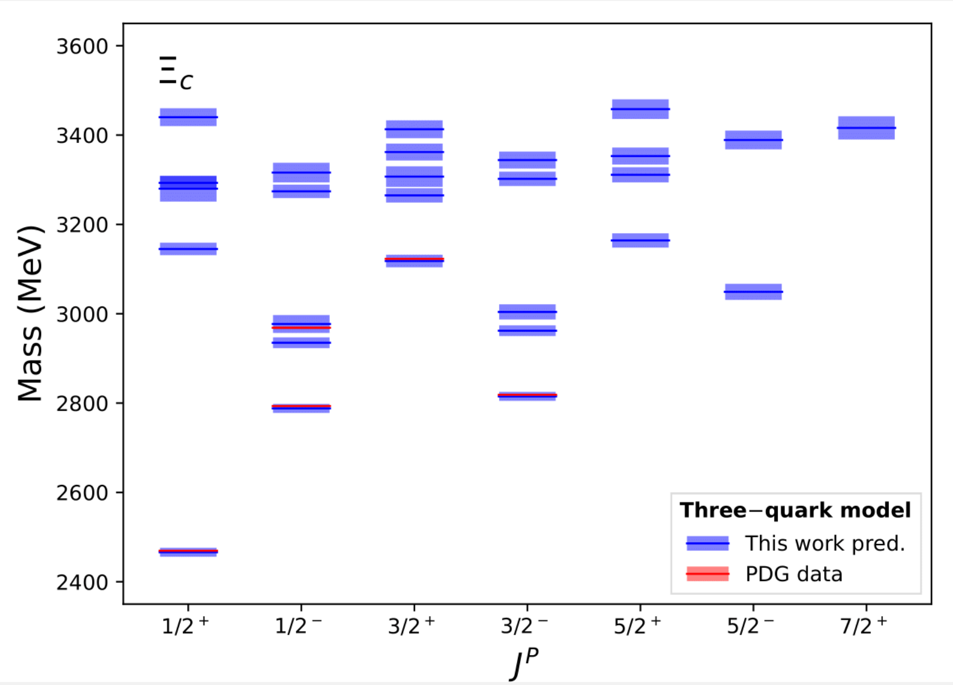
Two main decay channels



(a)$1P_\rho$-wave Λ_c states

Wen-Jia Wang, Li-Ye Xiao, XH, PRD106,074020（2022)

Ξ_c states $\underline{3}_F$



State	Ξ_c RQM [21]	NQM [22]	NQM [33]	PDG [24]
$1^2S\frac{1}{2}^+$	2476	2466	2470	2468
$1^2P_{\lambda}\frac{1}{2}^-$	2792	2773	2793	2792
$1^2P_{\lambda}\frac{3}{2}^-$	2819	2783	2820	2817
$1^2D_{\lambda\lambda}\frac{3}{2}^+$	3059	3012	3033	3055?
$1^2D_{\lambda\lambda}\frac{5}{2}^+$	3076	3004	3040	3080?

YX Yao, KL Wang, XH, PRD98,076015(2018)

PRD107,034031 (2023)

How to establish the missing D-wave states?

Candidates of the D-wave Ξ_c states

$\Xi_c(3055)$

M =3056 MeV,
Γ =7.8 MeV

	Mode
Γ_1	$\Sigma^{++} K^-$
Γ_2	ΛD^+

$\Gamma(\Lambda D^+)/\Gamma(\Sigma^{++} K^-)$

VALUE
$5.09 \pm 1.01 \pm 0.76$

$\Xi_c(3080)$

M =3077 MeV,
Γ =3.6 MeV

	Mode
Γ_1	$\Lambda_c^+ \overline{K} \pi$
Γ_2	$\Sigma_c(2455) \overline{K}$
Γ_3	$\Sigma_c(2455)^{++} K^-$
Γ_4	$\Sigma_c(2520)^{++} K^-$
Γ_5	$\Sigma_c(2455) \overline{K} + \Sigma_c(2520) \overline{K}$
Γ_8	ΛD^+

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

Our explaination with 1D states

Decay mode	M_f	$\vert\Xi_c{}^2D_{\lambda\lambda}\frac{3}{2}^+\rangle(3055)$ Γ_i (MeV)	$\vert\Xi_c{}^2D_{\lambda\lambda}\frac{5}{2}^+\rangle(3080)$ Γ_i (MeV)
$\Xi_c'\pi$	2575	$1.93^{+0.57}_{-0.61}$	$0.75^{-0.18}_{+0.27}$
$\Xi_c'^*\pi$	2645	$0.60^{-0.04}_{+0.07}$	$2.08^{+0.38}_{-0.40}$
$\Sigma_c K$	2455	$2.49^{+0.38}_{-0.29}$	$0.22^{<-0.01}_{+0.10}$
$\Sigma_c^* K$	2520	$0.14^{<-0.01}_{<+0.01}$	$1.68^{+0.11}_{-0.14}$
$\vert\Xi_c' 1^4P_{\lambda}\frac{1}{2}^-\rangle\pi$	2854	< 0.01	$1.42^{+0.39}_{-0.34}$
$\vert\Xi_c' 1^4P_{\lambda}\frac{3}{2}^-\rangle\pi$	2912	0.04	$0.20^{+0.04}_{-0.03}$
$\vert\Xi_c' 1^4P_{\lambda}\frac{5}{2}^-\rangle\pi$	2929	...	$0.54^{+0.10}_{-0.10}$
Sum		$5.20^{+0.91}_{-0.83}$	$6.90^{+0.84}_{-0.64}$

- ◆The predicted decay widths and main decay modes are consistent with the observations.
- ◆To be further confirmed, for some main decay modes are still missing.

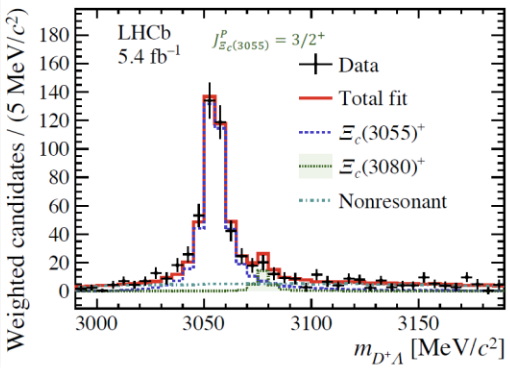
Lei-Hua Liu, Li-Ye Xiao, XH, PRD86,034024(2012)
YX Yao, KL Wang, XH, PRD98,076015(2018)

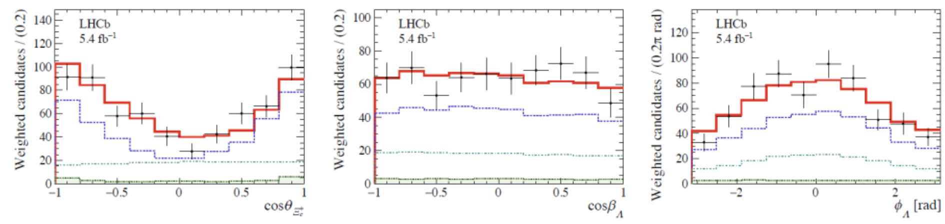
LHCb observation

arXiv:2409.05440

Run2, $\Xi_b^0 \to \Xi_c^{**+}\pi^-$ channel

Best fit projections: $J^P_{\Xi_c^{**}(3055)} = 3/2^+$





- $J^P_{\Xi_c^{**}(3055)} = 3/2^+, J^P_{\Xi_c^{**}(3080)} = 5/2^+, J^P_{NR} = 1/2^-$ (S-wave) as default

From Guanyue Wan's report

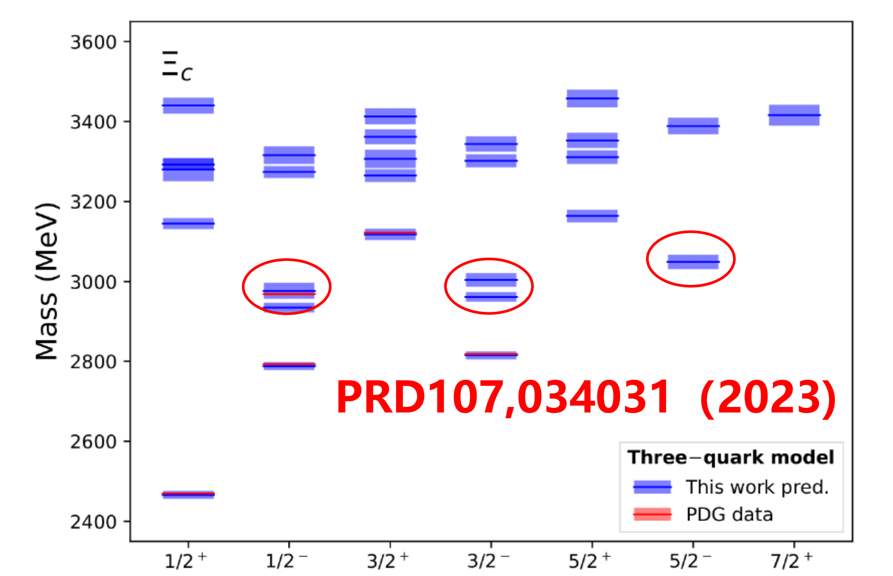
Theoretical interpretations of $\Xi_c(3055)$

References	Theoretical model	J^P of $\Xi_c(3055)$
Eur. Phys. J. A 37 (2008) 217–225	Faddeev method	$5/2^+$ (1D)
Phys. Rev. D 78 (2008) 056005	Regge phenomenology	$5/2^+$ (1D)
Phys. Rev. D 84 (2011) 014025	QCD-motivated relativistic quark model	$3/2^+$ (1D)
Phys. Rev. D 86 (2012) 034024	Chiral quark model	$3/2^+$ (1D)
Eur. Phys. J. A 82 (2015) 51	Relativistic flux tube model	$3/2^+$ (1D)
Phys. Rev. D 94 (2016) 114016	QCD sum rules within HQET	$3/2^+$ (1D)
Phys. Rev. D 96 (2017) 114003	3P0 model	$1/2^+(\bar{3}_F), 3/2^+(6_F)$ (2S)
Eur. Phys. J. C 79 (2019)167	Hadron molecular state	$1/2^-$, $3/2^-$ (molecular)

Looking for higher 2P Ξ_c states @ 3.1GeV

1D 3/2+:	Λ_c (2860)	Ξ_c (3055)
1D 5/2+:	Λ_c (2880)	Ξ_c (3080)?
2P 3/2-:	Λ_c (2940)	Ξ_c (3140)??
2P 1/2-:	Λ_c (2910)?	Ξ_c (3110)??

Looking for rho mode 1P Ξ_c states @ 3.0GeV

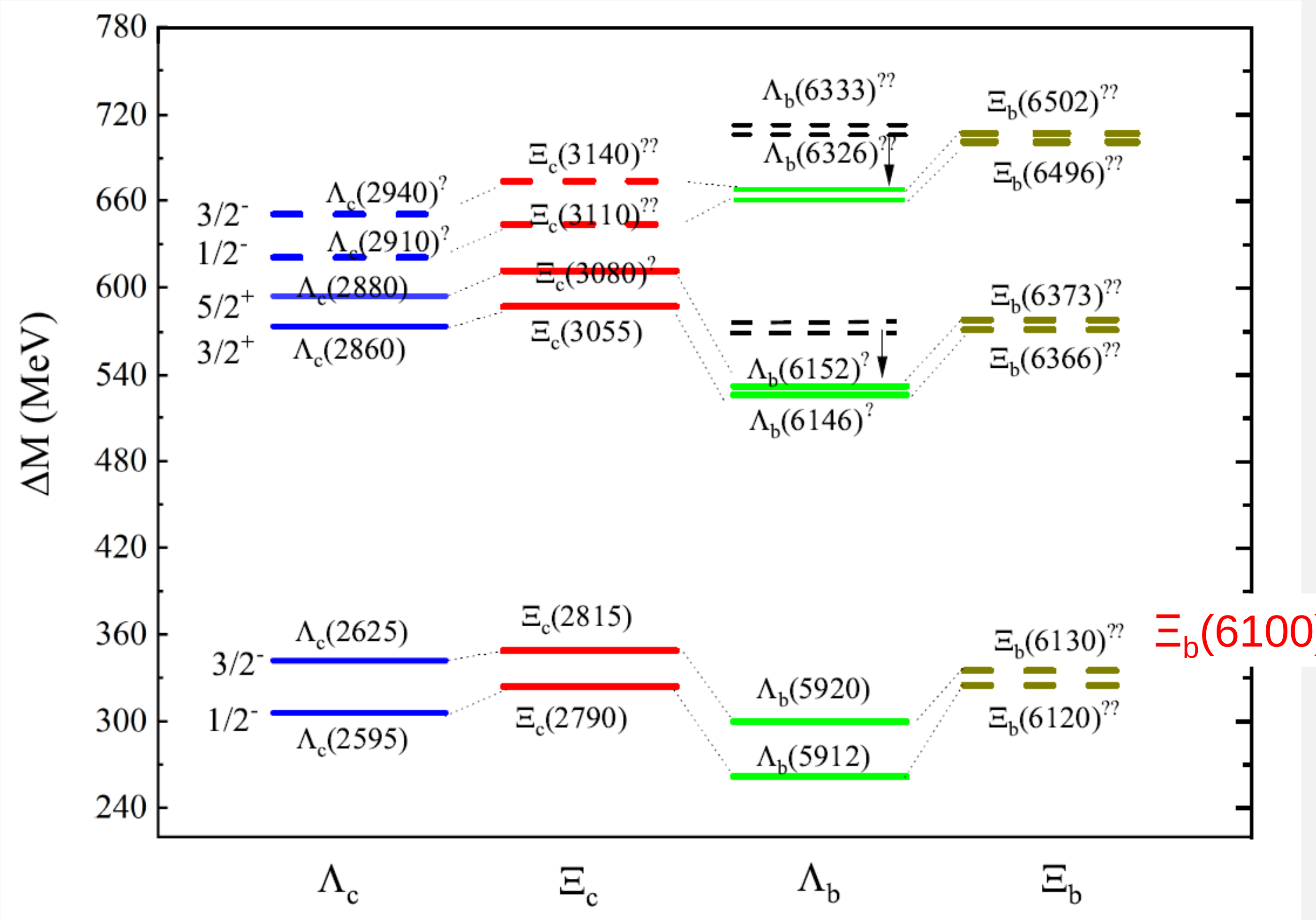


Several main decay channels are suggested to be observed in future experiments.

Wen-Jia Wang, Li-Ye Xiao, XH, PRD106,074020（2022)

Decay width	$\Xi_c\|J^P=\frac{1}{2}^-,0\rangle_\rho$ $M=2951$	$\Xi_c\|J^P=\frac{1}{2}^-,1\rangle_\rho$ $M=2980$	$\Xi_c\|J^P=\frac{3}{2}^-,1\rangle_\rho$ $M=2987$	$\Xi_c\|J^P=\frac{3}{2}^-,2\rangle_\rho$ $M=3016$	$\Xi_c\|J^P=\frac{5}{2}^-,2\rangle_\rho$ $M=3076$
$\Gamma[\Xi_c\pi]$	48.6	0.0	10.7	10.8	37.1
$\Gamma[\Lambda_c K]$	64.2	0.0	5.1	5.5	20.7
$\Gamma[\Xi_c'\pi]$	0.0	33.5	0.3	10.2	5.5
$\Gamma[\Sigma_c K]$	0.0	102.9	0.0	1.9	2.9
$\Gamma[\Xi_c^*\pi]$	0.0	1.9	16.1	17.9	3.5
$\Gamma[\Sigma_c^* K]$	...	...	...	11.5	0.6
$\Gamma[\Xi_c(2790)\pi]$	0.0	0.0	0.0	0.0	0.1
$\Gamma[\Xi_c(2815)\pi]$	0.0	0.0	0.0	0.0	0.1
Γ_{Total}	112.8	138.3	32.2	57.8	70.5

Summary for $\underline{3}_F$ states



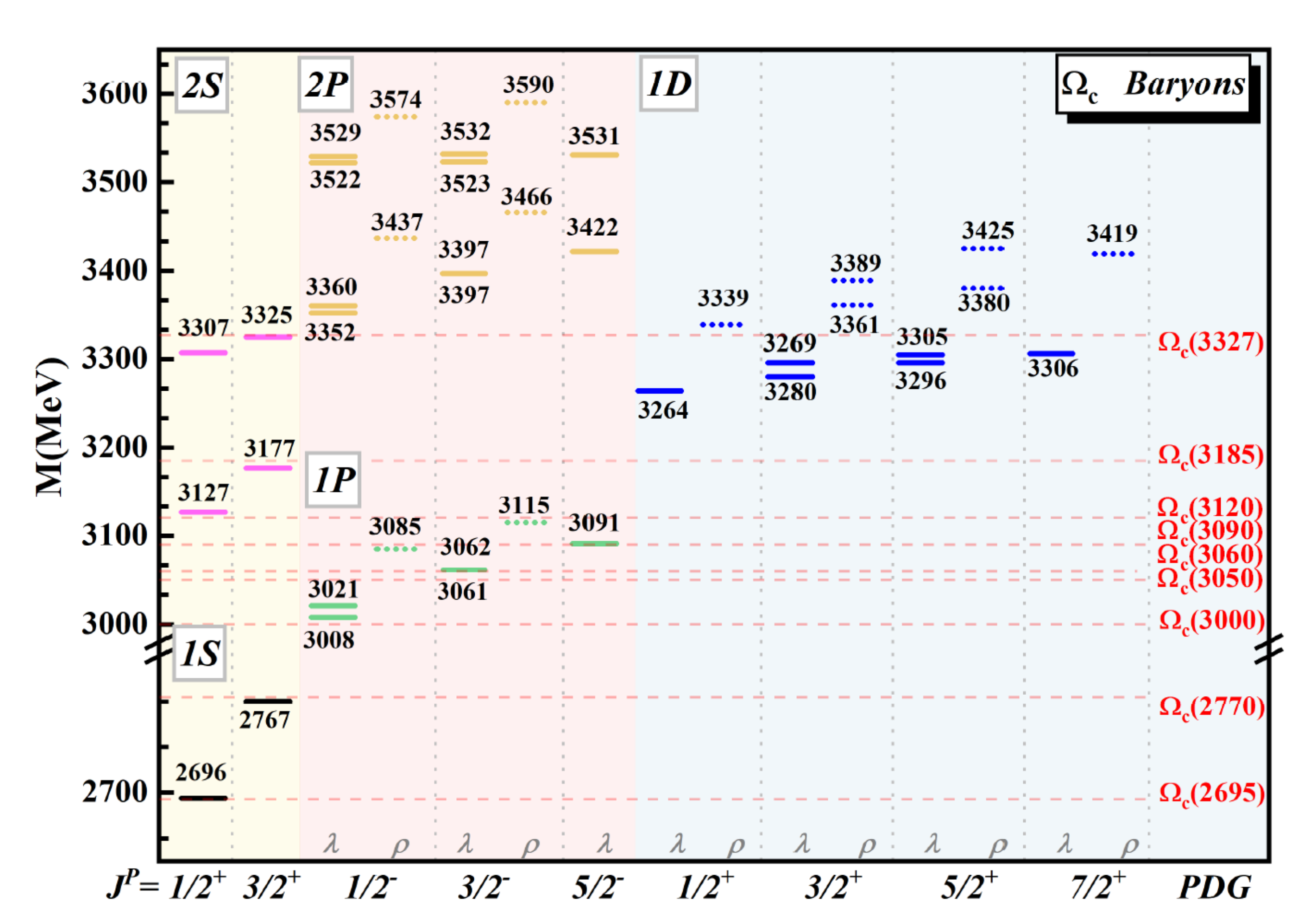
$\Xi_b(6100)$

Some predicted masses are taken from Ebert et al., arXiv:1105.0583.

Part II
Symmetric sextet

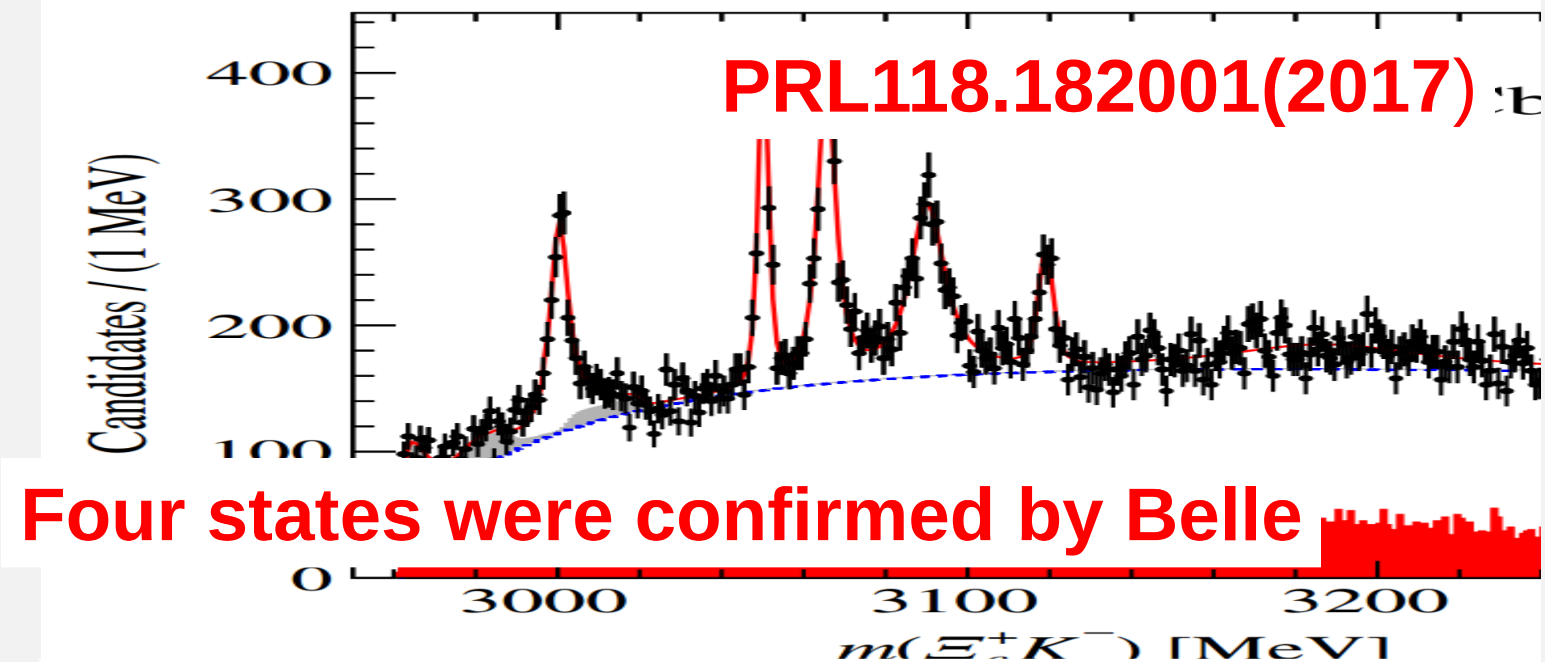
6_F states

Ω_c states



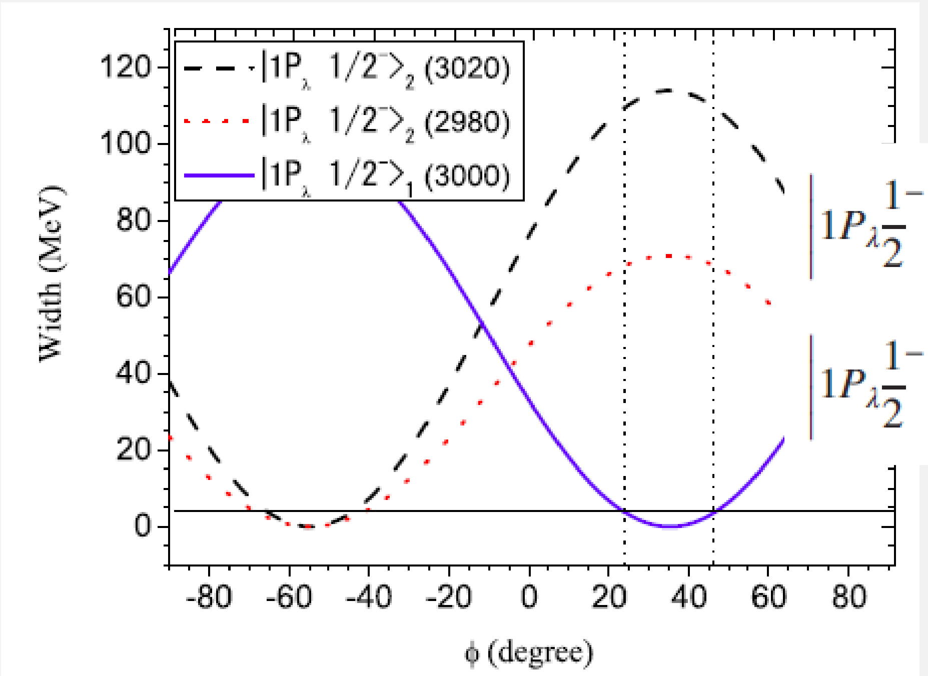
LHCb and Belle provide good oppertunities.

LHCb observed five excited Ω_c states!



Resonance	Mass (MeV)	Γ (MeV)
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$
		<1.2 MeV, 95% C.L.
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$

Our explaination



PRD95,116010 (2017)

$$\left|1P_{\lambda}\frac{1}{2}^{-}\right\rangle_1 = +\cos(\phi)\left|1^2P_{\lambda}\frac{1}{2}^{-}\right\rangle + \sin(\phi)\left|1^4P_{\lambda}\frac{1}{2}^{-}\right\rangle,$$

$$\left|1P_{\lambda}\frac{1}{2}^{-}\right\rangle_2 = -\sin(\phi)\left|1^2P_{\lambda}\frac{1}{2}^{-}\right\rangle + \cos(\phi)\left|1^4P_{\lambda}\frac{1}{2}^{-}\right\rangle,$$

State	Mass	$\Gamma(\Xi_c\bar{K})$	$\Gamma(\Xi_c'\bar{K})$	$\Gamma[\Omega_c(2695)\gamma]$	$\Gamma[\Omega_c(2770)\gamma]$	$\Gamma^{\rm th}_{\rm total}$	$\Gamma^{\rm exp}_{\rm total}$	Possible assignment
$\lvert 1P_{\lambda}\frac{1}{2}^{-}\rangle_1$	3000	4.0	$\cdots$	0.36/0.20	0.02/0.08	4.38/4.28	4.5 ± 0.9	$\Omega_c(3000)$
$\lvert 1^4P_{\lambda}\frac{3}{2}^{-}\rangle$	3050	0.61	$\cdots$	1.12×10^{-3}	0.33	0.94	0.8 ± 0.3	$\Omega_c(3050)$
$\lvert 1^2P_{\lambda}\frac{3}{2}^{-}\rangle$	3066	4.61	$\cdots$	0.35	5.68×10^{-4}	4.96	3.5 ± 0.4	$\Omega_c(3066)$
$\lvert 1^4P_{\lambda}\frac{5}{2}^{-}\rangle$	3090	9.32	0.03	1.00×10^{-4}	0.18	9.53	8.7 ± 1.8	$\Omega_c(3090)$

Conslusion

- Ω_c (3000,3050,3066,3090) may be 1P-wave states with very narrow width.

- Ω_c(3119) may be a 2S state or other assignment.

- A broad 1P wave state is waiting to be found!
- Radiative decay is worth observing.

Looking for D-wave Ω_c states @ 3.3 GeV

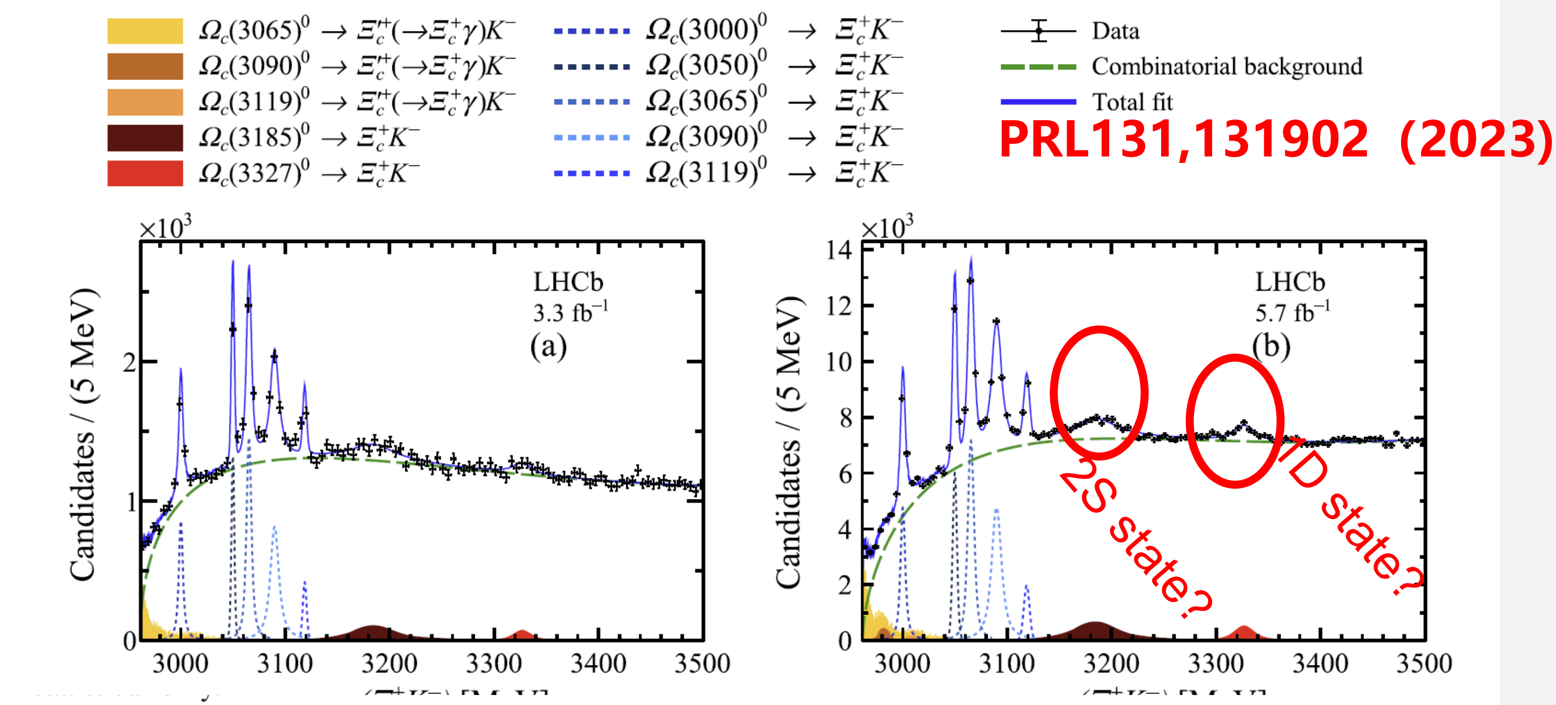
		$\vert\Omega_c\,{}^2D_{\lambda\lambda\frac{3}{2}^+}\rangle(3282)$		$\vert\Omega_c\,{}^2D_{\lambda\lambda\frac{5}{2}^+}\rangle(3286)$		$\vert\Omega_c\,{}^4D_{\lambda\lambda\frac{1}{2}^+}\rangle(3287)$		$\vert\Omega_c\,{}^4D_{\lambda\lambda\frac{3}{2}^+}\rangle(3298)$		$\vert\Omega_c\,{}^4D_{\lambda\lambda\frac{5}{2}^+}\rangle(3297)$		$\vert\Omega_c\,{}^4D_{\lambda\lambda\frac{7}{2}^+}\rangle(3283)$	
Decay mode	M_f	Γ_i	$\mathcal{B}_i$ (%)	Γ_i	$\mathcal{B}_i$ (%)	Γ_i	$\mathcal{B}_i$ (%)	Γ	$\mathcal{B}_i$ (%)	Γ_i	$\mathcal{B}_i$ (%)	Γ_i	$\mathcal{B}_i$ (%)
$\Xi_c K$	2470	$7.97^{+3.85}_{-3.61}$	44.7	$5.16^{-1.13}_{+1.42}$	57.3	$15.9^{+7.8}_{-7.2}$	71.4	$7.90^{+4.08}_{-3.73}$	48.2	$1.65^{-0.35}_{+0.44}$	19.8	$6.43^{-1.43}_{+1.77}$	81.7
$\Xi'_c K$	2575	$9.26^{+2.34}_{-2.55}$	51.9	$1.77^{-0.45}_{+0.64}$	19.7	$4.71^{+1.22}_{-1.34}$	20.8	$2.44^{+0.68}_{-0.73}$	14.8	$0.15^{-0.04}_{+0.05}$	1.79	$0.54^{-0.14}_{+0.20}$	6.73
$\Xi'^*_c K$	2645	$0.50^{-0.01}_{+0.02}$	2.8	$2.05^{+0.28}_{-0.32}$	22.8	$1.65^{+0.25}_{-0.31}$	7.4	$5.97^{+0.90}_{-1.03}$	36.4	$6.61^{-0.60}_{+0.64}$	79.2	$0.88^{+0.11}_{-0.12}$	11.2
$\vert\Omega_c\,1^2P_{\lambda\frac{1}{2}^-}\rangle\gamma$	3000	$91.8^{-14.5}_{+18.8}$	0.51	$9.79^{-1.60}_{+2.12}$	0.11	0.03	<0.01	$0.49^{-0.05}_{+0.06}$	<0.01	$0.19^{-0.02}_{+0.02}$	<0.01	$\simeq 0.0$	<0.01
$\vert\Omega_c\,1^2P_{\lambda\frac{3}{2}^-}\rangle\gamma$	3066	$18.4^{-3.1}_{+4.0}$	0.10	$39.7^{-6.7}_{+8.9}$	0.44	0.04	<0.01	0.02	<0.01	$0.17^{-0.02}_{+0.02}$	<0.01	$0.13^{-0.02}_{+0.02}$	<0.01
$\vert\Omega_c\,1^4P_{\lambda\frac{1}{2}^-}\rangle\gamma$	3050	$0.13^{-0.02}_{+0.01}$	<0.01	0.008	<0.01	$70.3^{-11.3}_{+14.8}$	0.32	$34.7^{-5.6}_{+7.3}$	0.21	$5.56^{-0.91}_{+1.20}$	0.07	$1.07^{-0.21}_{+0.30}$	0.01
$\vert\Omega_c\,1^4P_{\lambda\frac{3}{2}^-}\rangle\gamma$	3050	$0.2^{-0.03}_{+0.03}$	<0.01	0.09	<0.01	$27.5^{-4.5}_{+5.9}$	0.12	$54.1^{-8.8}_{+11.4}$	0.33	$39.8^{-6.6}_{+8.6}$	0.47	$5.62^{-0.94}_{+1.23}$	0.07
$\vert\Omega_c\,1^4P_{\lambda\frac{5}{2}^-}\rangle\gamma$	3090	0.03	<0.01	$0.14^{-0.02}_{+0.03}$	<0.01	$2.44^{-0.45}_{+0.62}$	<0.10	$7.95^{-1.36}_{+1.82}$	0.05	$19.6^{-3.3}_{+4.3}$	0.24	$23.1^{-3.9}_{+5.3}$	0.29
Sum		$17.84^{+6.16}_{-6.16}$		$9.03^{-1.30}_{+1.73}$		$22.33^{+9.25}_{-8.83}$		$16.21^{+5.64}_{-5.47}$		$8.34^{-0.98}_{+1.11}$		$7.82^{-1.46}_{+1.85}$	

Decay widths are relatively narrow (about 10-20 MeV).

Decay modes Ξ_cK, Ξ'_cK, Ξ'_c*K are worth observing!

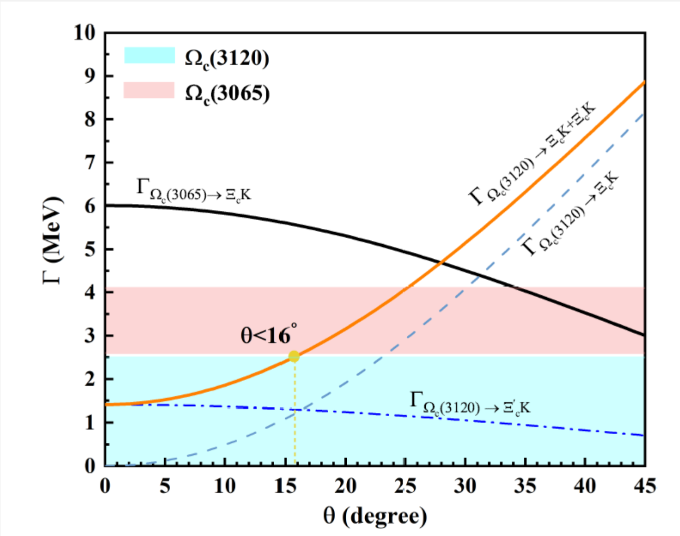
YX Yao, KL Wang, XH, PRD98,076015(2018)

New Ω_c states observed at LHCb



Resonance	m (MeV)	Γ (MeV)	Yield (dataset 1)	Yield (dataset 2)
$\Omega_c(3000)^0$	3000.44 ± 0.07	3.83 ± 0.23	1225 ± 83	7533 ± 263
$\Omega_c(3050)^0$	3050.18 ± 0.04	0.67 ± 0.17	1139 ± 65	7379 ± 215
$\Omega_c(3065)^0$	3065.63 ± 0.06	3.79 ± 0.20	2180 ± 99	13046 ± 316
$\Omega_c(3090)^0$	3090.16 ± 0.11	8.48 ± 0.44	2234 ± 136	14434 ± 486
$\Omega_c(3119)^0$	3118.98 ± 0.12	0.60 ± 0.63	470 ± 66	3279 ± 234
$\Omega_c(3185)^0$	3185.1 ± 1.7	50 ± 7	1642 ± 367	10278 ± 1565
$\Omega_c(3327)^0$	3327.1 ± 1.2	20 ± 5	489 ± 173	3649 ± 723

Our new explaination: Ω_c (3120) arXiv:2502.13741



May be a rho mode 1P state with JP=3/2, slightly mixed with the lambda mode.

As the 2S states, the predicted width is too broad.

TABLE VI: The partial decay widths (MeV) of the excited states of Ω_c. Γ^{th}_{sum} stands for the sum of partial widths.

State	Mass	$\Gamma[\Xi_c K]$	$\Gamma[\Xi_c^{\prime} K]$	$\Gamma[\Xi_c^{\prime *} K]$	$\Gamma[\Omega_c \eta]$	$\Gamma[\Omega_c(2770)\eta]$	$\Gamma[\Xi_c(2790)K]$	$\Gamma[\Xi_c(2815)K]$	Γ^{th}_{sum}
$\lvert J^P=1/2^-,0\rangle_{1P_\lambda}$	3021	97.25	-	-	-	-	-	-	97.25
$\lvert J^P=1/2^-,1\rangle_{1P_\lambda}$	3008	~ 0	-	-	-	-	-	-	~ 0
$\lvert J^P=3/2^-,1\rangle_{1P_\lambda}$	3062	~ 0	-	-	-	-	-	-	~ 0
$\lvert J^P=3/2^-,2\rangle_{1P_\lambda}$	3061	6.39	-	-	-	-	-	-	6.39
$\lvert J^P=5/2^-,2\rangle_{1P_\lambda}$	3091	12.21	0.04	-	-	-	-	-	12.25
$\lvert J^P=1/2^-,1\rangle_{1P_\rho}$	3085	~ 0	42.35	-	-	-	-	-	42.35
$\lvert J^P=3/2^-,1\rangle_{1P_\rho}$	3115	~ 0	1.07	-	-	-	-	-	1.07
$\lvert J^P=1/2^+,1\rangle_{2_1S}$	3127	71.21	25.39	-	-	-	-	-	96.60
$\lvert J^P=1/2^+,1\rangle_{2_2S}$	3307	21.27	23.92	8.97	0.33	-	8.52	-	63.01
$\lvert J^P=3/2^+,1\rangle_{2_1S}$	3177	40.17	7.34	10.08	-	-	-	-	57.59
$\lvert J^P=3/2^+,1\rangle_{2_2S}$	3325	23.96	7.45	30.15	0.30	0.03	0.04	~ 0	61.93

Our explaination: Ω_c (3185)

The observed mass, width, and decay mode are consistent with the assignment of 2S state with JP=3/2+.

$\Omega_c(3185)^0$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{3185 \pm 1.7^{+7.4}_{-0.9} \pm 0.2}$	12k	[1] AAIJ	23AS	LHCB	pp at 7, 8, 13 TeV

[1] The third uncertainty is due to the uncertainty in the Ξ_c^+ mass, taken to be the PDG 22 fit result 2467.71 ± 0.23 MeV.

$\Omega_c(3185)^0$ WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{50 \pm 7^{+10}_{-20}}$	12k	AAIJ	23AS	LHCB	pp at 7, 8, 13 TeV

Predictions: Mass: 3177 MeV, Width: 58 MeV

Our explaination: Ω_c (3327)

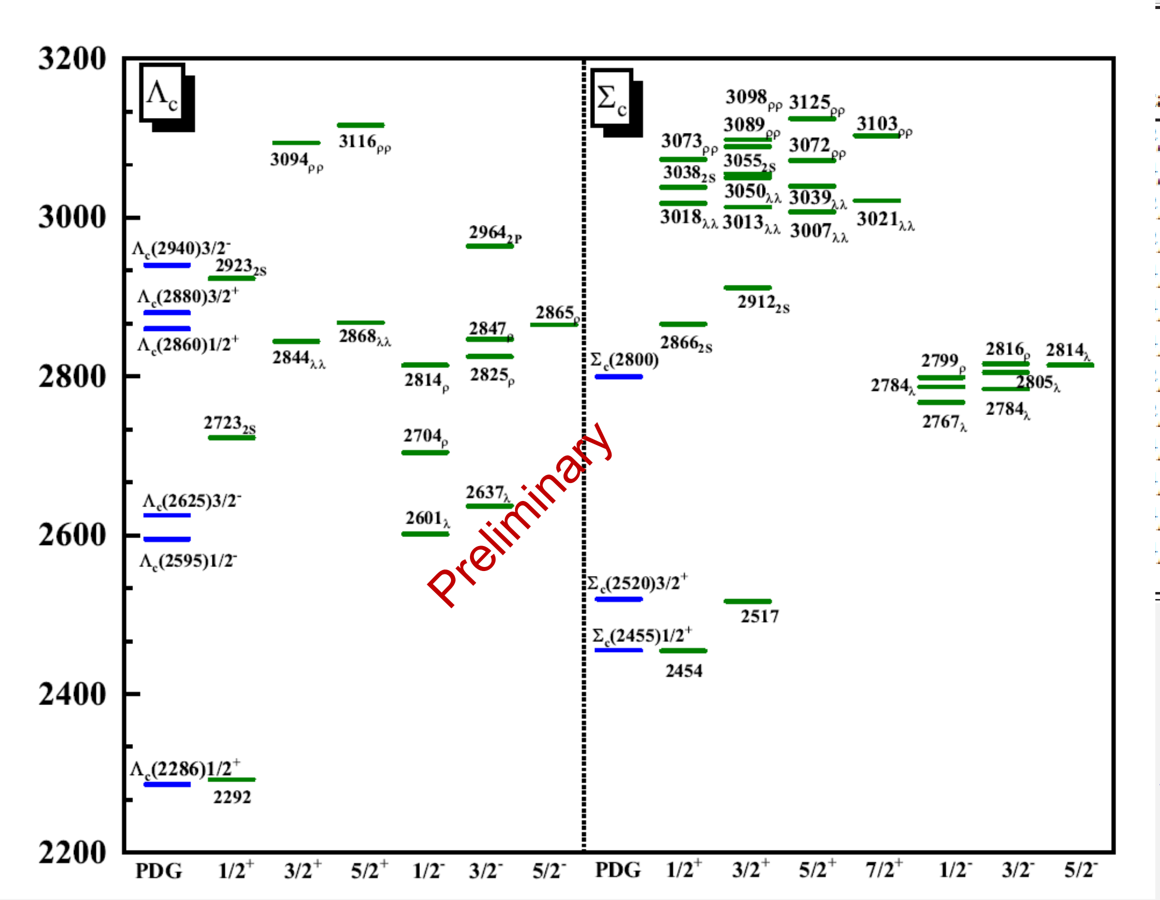
This state may favor the assignment of 1D state with JP=5/2+ or 7/2+.

TABLE VII: The strong decay widths (MeV) of $|J^P = 3/2^+, 1\rangle_{1D_\lambda}$, $|J^P = 5/2^+, 3\rangle_{1D_\lambda}$, $|J^P = 7/2^+, 3\rangle_{1D_\lambda}$, and $|J^P = 1/2^+, 1\rangle_{1D_\rho}$ as the candidates of $\Omega_c(3327)$. Γ^{th}_{lps} stands for the sum of the partial widths for the K and η emitting channels.

States	Γ^{th}_{lps}	$\Gamma[\Xi D]$	$\Gamma[\Xi D^*]$	Γ^{th}	Γ^{exp} [78]
$\|J^P = 3/2^+, 1\rangle_{1D_\lambda}$	70.8	5.6	0.24	76.6	20^{+14}_{-5}
$\|J^P = 5/2^+, 3\rangle_{1D_\lambda}$	11.8	0.14	0.02	12.0	
$\|J^P = 7/2^+, 3\rangle_{1D_\lambda}$	10.1	5.1	~ 0	15.2	
$\|J^P = 1/2^+, 1\rangle_{1D_\rho}$	8.9	-	-	8.9	

The DΞ channel is worth observing!

Σ_c states



	Σ_c			
ate	RQM [21]	NQM [27]	NQM [33]	PDG [24]
$S\frac{1}{2}^+$	2443	2460	2456	2455
$S\frac{3}{2}^+$	2519	2523	2515	2520
$P_{\lambda}\frac{1}{2}^-$	2713	2802	2702	?
$P_{\lambda}\frac{3}{2}^-$	2798	2807	2785	?
$P_{\lambda}\frac{1}{2}^-$	2799	2826	2765	?
$P_{\lambda}\frac{3}{2}^-$	2773	2837	2798	?
$P_{\lambda}\frac{5}{2}^-$	2789	2839	2790	?
$D_{\lambda\lambda}\frac{3}{2}^+$	3043	3065	2952	?
$D_{\lambda\lambda}\frac{5}{2}^+$	3038	3099	2942	?
$D_{\lambda\lambda}\frac{1}{2}^+$	3041	3103	2949	?
$D_{\lambda\lambda}\frac{3}{2}^+$	3040	3094	2964	?
$D_{\lambda\lambda}\frac{5}{2}^+$	3023	3114	2962	?
$D_{\lambda\lambda}\frac{7}{2}^+$	3013	...	2943	?

The high-lying 1P,1D states highly overlap with each other .

Only the ground states are established!

Decay properties of the P-wave Σ_c states

Relatively narrow states!

$\lvert {}^{2S+1}L_{\lambda} J^P\rangle$	Σ_c states	Channel	Γ_i (MeV)	$\mathcal{B}_i$
$\lvert {}^2P_{\lambda}\frac{1}{2}^-\rangle$	$\Sigma_c(2713)$	$\Lambda_c\pi$	6.49	28.65%
		$\Sigma_c\pi$	16.08	70.99%
		$\Sigma_c^*\pi$	0.08	0.35%
		total	22.65	
$\lvert {}^2P_{\lambda}\frac{3}{2}^-\rangle$	$\Sigma_c(2798)$	$\Lambda_c\pi$	22.53	61.73%
		$\Sigma_c\pi$	8.84	24.22%
		$\Sigma_c^*\pi$	5.13	14.05%
		total	36.5	
$\lvert {}^4P_{\lambda}\frac{1}{2}^-\rangle$	$\Sigma_c(2799)$	$\Lambda_c\pi$	6.66	37.78%
		$\Sigma_c\pi$	10.30	58.42%
		$\Sigma_c^*\pi$	0.67	3.80%
		total	17.63	
$\lvert {}^4P_{\lambda}\frac{3}{2}^-\rangle$	$\Sigma_c(2773)$	$\Lambda_c\pi$	3.62	14.66%
		$\Sigma_c\pi$	0.29	1.17%
		$\Sigma_c^*\pi$	20.78	84.16%
		total	24.69	
$\lvert {}^4P_{\lambda}\frac{5}{2}^-\rangle$	$\Sigma_c(2789)$	$\Lambda_c\pi$	25.03	75.35%
		$\Sigma_c\pi$	2.29	6.89%
		$\Sigma_c^*\pi$	5.90	17.76%
		total	33.22	

State	$\lvert J^P, j\rangle$	Channel	Γ_i	$\mathcal{B}_i$
$\Sigma_c(2746)$	$\lvert J^P=1/2^-,1\rangle$	$\Lambda_c\pi$	$\cdots$	$\cdots$
		$\Sigma_c\pi$	28.06	98.00%
		$\Sigma_c^*\pi$	0.47	2.00%
		total	28.53	
$\Sigma_c(2755)$	$\lvert J^P=1/2^-,0\rangle$	$\Lambda_c\pi$	15.23	100.00%
		$\Sigma_c\pi$	$\cdots$	$\cdots$
		$\Sigma_c^*\pi$	$\cdots$	$\cdots$
		total	15.23	
$\Sigma_c(2796)$	$\lvert J^P=3/2^-,1\rangle$	$\Lambda_c\pi$	$\cdots$	$\cdots$
		$\Sigma_c\pi$	3.21	10.43%
		$\Sigma_c^*\pi$	27.57	89.57%
		total	30.78	
$\Sigma_c(2813)$	$\lvert J^P=3/2^-,2\rangle$	$\Lambda_c\pi$	30.59	75.42%
		$\Sigma_c\pi$	7.53	18.57%
		$\Sigma_c^*\pi$	2.44	6.01%
		total	40.56	
$\Sigma_c(2840)$	$\lvert J^P=5/2^-,2\rangle$	$\Lambda_c\pi$	37.63	73.96%
		$\Sigma_c\pi$	4.90	9.63%
		$\Sigma_c^*\pi$	8.35	16.41%
		total	50.88	

KL Wang, YX Yao, XH, QZ, PRD96,116016(2017)

KL Wang, XH, CPC46,023103(2022)

Evidence of the P-wave Σ_c states from Exp.

$\Sigma_c(2800)$

$I(J^P) = 1(?^?)$ Status: ∗∗∗

Seen in the $\Lambda_c^+\pi^+$, $\Lambda_c^+\pi^0$, and $\Lambda_c^+\pi^-$ mass spectra.

$\Sigma_c(2800)^{++}$ WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{75^{+18}_{-13}{}^{+12}_{-11}}$	$2810^{+1090}_{-\ \ 775}$	MIZUK	05	BELL	$e^+e^- \approx \Upsilon(4S)$

$\Sigma_c(2800)^{+}$ WIDTH

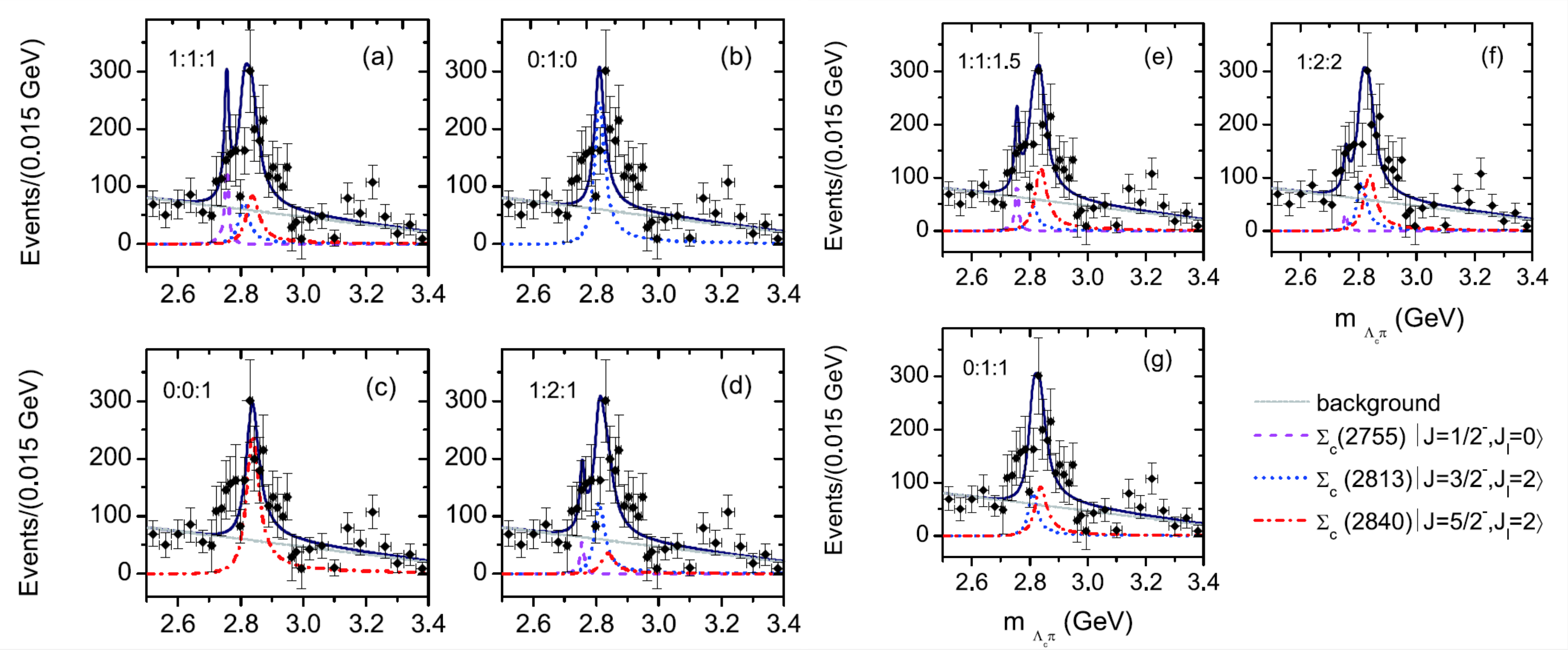
VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{62^{+37}_{-23}{}^{+52}_{-38}}$	1540^{+1750}_{-1050}	MIZUK	05	BELL	$e^+e^- \approx \Upsilon(4S)$

$\Sigma_c(2800)^{0}$ WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{72^{+22}_{-15}}$ **OUR AVERAGE**					
$86^{+33}{}^{+12}$		AUBERT	08BN	BABR	$B^- \to \bar{p}\Lambda_c^+\pi^-$

- A good candidate of P wave state with $J^P=3/2^-$ or $5/2^-$!
- Looking for more P wave states in the $\Sigma_c^{(*)}\pi$ final states.

The roles of P-wave Σc states in the Λcπ invariant mass spectrum



Three states with JP=1/2-,3/2- and 5/2- may highly overlap!

KL Wang, XH, CPC46,023103(2022)

Decay properties of the D-wave Σ_c states

		$\vert\Sigma_c{}^2D_{\lambda\lambda\frac{3}{2}^+}\rangle(3043)$	$\vert\Sigma_c{}^2D_{\lambda\lambda\frac{5}{2}^+}\rangle(3038)$	$\vert\Sigma_c{}^4D_{\lambda\lambda\frac{1}{2}^+}\rangle(3041)$	$\vert\Sigma_c{}^4D_{\lambda\lambda\frac{3}{2}^+}\rangle(3040)$	$\vert\Sigma_c{}^4D_{\lambda\lambda\frac{5}{2}^+}\rangle(3023)$	$\vert\Sigma_c{}^4D_{\lambda\lambda\frac{7}{2}^+}\rangle(3013)$
Decay mode	M_f	Γ_i (MeV)	Γ_i (MeV)	Γ_i (MeV)	Γ_i (MeV)	Γ_i (MeV)	Γ_i (MeV)
$\Lambda_c\pi$	2286	$1.29^{+2.54}_{-1.22}$	$11.9^{-1.65}_{+1.51}$	$2.62^{+5.09}_{-2.46}$	$1.15^{+2.32}_{-1.09}$	$3.1^{-0.46}_{+0.42}$	$13.1^{-2.06}_{+1.83}$
$\Sigma_c\pi$	2455	$7.06^{+4.66}_{-3.95}$	$8.78^{-1.86}_{+2.25}$	$3.53^{+2.31}_{-1.96}$	$1.77^{+1.14}_{-0.98}$	$0.54^{-0.11}_{+0.14}$	$2.18^{-0.48}_{+0.60}$
$\Sigma_c^*\pi$	2520	$2.44^{-0.33}_{+0.48}$	$2.91^{+0.72}_{-0.61}$	$1.71^{+0.79}_{-0.76}$	$7.47^{+2.04}_{-1.77}$	$11.6^{+0.80}_{-0.34}$	$1.45^{+0.13}_{-0.02}$
$\Xi_c K$	2470	$1.17^{+0.12}_{-0.14}$	0.03	$2.27^{+0.22}_{-0.27}$	$1.12^{+0.10}_{-0.13}$	< 0.01	0.01
$\vert\Lambda_c{}^2P_{\lambda\frac{1}{2}^-}\rangle\pi$	2592	$4.93^{+0.25}_{-0.19}$	$10.3^{-0.83}_{+0.68}$	$52.6^{-3.2}_{+2.7}$	$3.06^{+2.44}_{-1.70}$	$11.2^{-0.8}_{+0.9}$	$11.1^{+3.5}_{-3.0}$
$\vert\Lambda_c{}^2P_{\lambda\frac{3}{2}^-}\rangle\pi$	2628	$52.8^{+6.76}_{-5.77}$	$10.9^{+2.1}_{-2.4}$	$64.0^{+22.2}_{-18.8}$	$43.1^{+4.4}_{-3.7}$	$1.92^{+0.02}_{<+0.01}$	$24.2^{+0.05}_{-0.04}$
$\vert\Sigma_c{}^2P_{\lambda\frac{1}{2}^-}\rangle\pi$	2713	$4.09^{+0.35}_{-0.29}$	$5.85^{-0.75}_{+0.86}$	$7.56^{-0.77}_{+0.89}$	$2.10^{+0.99}_{-0.82}$	$1.13^{-0.16}_{+0.18}$	$2.83^{+0.76}_{-0.68}$
$\vert\Sigma_c{}^2P_{\lambda\frac{3}{2}^-}\rangle\pi$	2798	$25.6^{+4.82}_{-4.29}$	$0.76^{-0.05}_{+0.18}$	$15.8^{+4.0}_{-3.6}$	$3.58^{+0.39}_{-0.34}$	0.01	$0.95^{+0.06}_{-0.04}$
$\vert\Sigma_c{}^4P_{\lambda\frac{1}{2}^-}\rangle\pi$	2799	0.09	$1.30^{+0.38}_{-0.33}$	$0.46^{-0.07}_{+0.10}$	$22.4^{+3.4}_{-3.0}$	$12.1^{+2.1}_{-1.9}$	< 0.01
$\vert\Sigma_c{}^4P_{\lambda\frac{3}{2}^-}\rangle\pi$	2773	$3.42^{+0.22}_{-0.16}$	$1.26^{+0.11}_{-0.09}$	$4.18^{+0.05}_{+0.02}$	$18.9^{+2.4}_{-2.0}$	$4.54^{+2.16}_{-1.80}$	$1.03^{-0.03}_{+0.04}$
$\vert\Sigma_c{}^4P_{\lambda\frac{5}{2}^-}\rangle\pi$	2789	$2.20^{+0.06}_{<+0.01}$	$4.51^{+0.57}_{-0.45}$	$6.1^{+1.96}_{-1.72}$	$16.8^{+4.8}_{-4.3}$	$23.0^{+3.3}_{-2.9}$	$1.26^{-0.05}_{+0.09}$
Sum		$105^{+19.5}_{-15.5}$	$58.5^{-1.3}_{+1.6}$	$160.8^{+32.6}_{-25.9}$	$121.5^{+24.4}_{-19.8}$	$69.1^{+6.9}_{-5.3}$	$58.1^{+1.9}_{-1.2}$

Broader than the P wave states.

The $J^P=5/2^+$ and $7/2^+$ states are worth observing!

YX Yao, KL Wang, XH, PRD98,076015(2018)

jj coupling scheme, 3P0 model & ChQM

TABLE IV. The strong decay properties of the λ-mode $1D$-wave Σ_c states, which masses are taken from the predictions in Ref. [54]. Γ_{Total} stands for the total decay width. The unit of the width and mass is MeV.

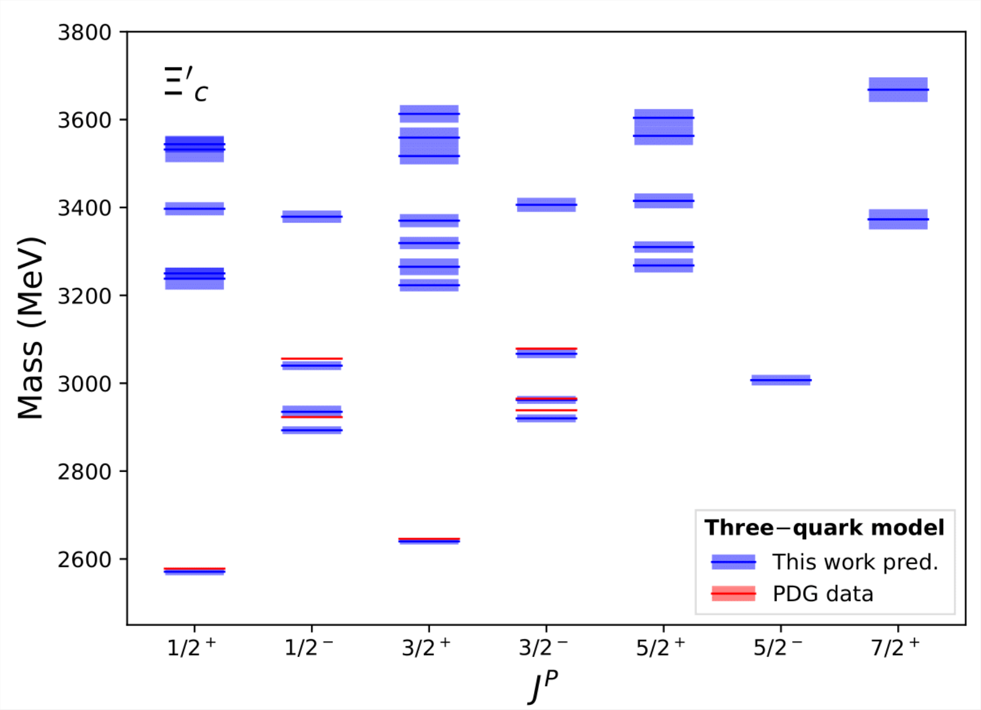
	$\Sigma_c\lvert J^P=\frac{1}{2}^+,1\rangle_{\lambda\lambda}$		$\Sigma_c\lvert J^P=\frac{3}{2}^+,1\rangle_{\lambda\lambda}$		$\Sigma_c\lvert J^P=\frac{3}{2}^+,2\rangle_{\lambda\lambda}$		$\Sigma_c\lvert J^P=\frac{5}{2}^+,2\rangle_{\lambda\lambda}$		$\Sigma_c\lvert J^P=\frac{5}{2}^+,3\rangle_{\lambda\lambda}$		$\Sigma_c\lvert J^P=\frac{7}{2}^+,3\rangle_{\lambda\lambda}$	
	$M=3041$		$M=3043$		$M=3040$		$M=3038$		$M=3023$		$M=3013$	
Decay width	QPC	ChQM	QPC	ChQM	QPC	ChQM	QPC	ChQM	QPC	ChQM	QPC	ChQM
$\Gamma[DN]$	17.1	...	1.1	...	9.6	...	0.3	...	...	...	0.6	...
$\Gamma[D^*N]$	3.9	...	7.5	...	4.6	...	6.8	...	0.1	...	...	...
$\Gamma[\Sigma_c\pi]$	2.5	3.5	0.7	0.9	5.3	7.9	0.3	4.8	0.3	4.7	0.1	2.4
$\Gamma[\Lambda_c\pi]$	2.8	2.3	2.4	2.2	0.1	...	...	...	0.7	15.5	0.6	14.5
$\Gamma[\Sigma_c^*\pi]$	1.0	1.7	2.8	4.3	3.5	6.0	5.5	10.8	0.2	5.2	0.2	1.5
$\Gamma[\Xi_c K]$	0.9	3.4	0.8	3.6	...	...	...	...	...	...	...	...
$\Gamma[\Lambda_c\lvert J^P=\frac{1}{2}^-,1\rangle_\lambda\pi]$	37.2	13.8	...	8.1	0.4	0.2	0.2	...	1.7	2.2	...	...
$\Gamma[\Lambda_c\lvert J^P=\frac{3}{2}^-,1\rangle_\lambda\pi]$	0.1	1.4	37.3	10.8	0.3	0.2	0.5	1.9	0.3	1.2	1.0	8.0
$\Gamma[\Sigma_c\lvert J^P=\frac{1}{2}^-,0\rangle_\lambda\pi]$	4.3	0.3	...	0.4	0.2	1.3	...	0.5	...	0.2	1.0	...
$\Gamma[\Sigma_c\lvert J^P=\frac{1}{2}^-,1\rangle_\lambda\pi]$	27.9	24.9	0.3	0.5	0.5	4.3	0.2	0.1	...	3.9	0.8	...
$\Gamma[\Sigma_c\lvert J^P=\frac{3}{2}^-,1\rangle_\lambda\pi]$	...	3.4	6.7	0.6	4.0	2.9	2.0	0.1	2.3	...	2.7	0.1
$\Gamma[\Sigma_c\lvert J^P=\frac{3}{2}^-,2\rangle_\lambda\pi]$	...	1.5	4.6	0.3	55.6	22.9	0.5	...	1.0	0.3	0.5	0.2
$\Gamma[\Sigma_c\lvert J^P=\frac{5}{2}^-,2\rangle_\lambda\pi]$	14.7	0.9	3.3	1.3	5.0	0.9	8.6	7.6	6.9	0.8	1.4	0.4
Γ_{Total}	112.4	57.0	67.5	33.0	89.1	46.6	24.9	25.8	13.5	34.0	8.9	27.1

The predicted main decay modes are often consistent in two models.

The DN channel is suggested to observe!

YH Zhou, WJ Wang, LY Xiao, XH, PRD108,014019（2023）

Ξ'_c states



State	RQM [21]	NQM [22]	NQM [33]	PDG [24]
	Ξ'_c			
$1^2S_{\frac{1}{2}^+}$	2579	2592	2579	2575
$1^4S_{\frac{3}{2}^+}$	2649	2650	2649	2645
$1^2P_{\lambda\frac{1}{2}^-}$	2936	2859	2839	?
$1^2P_{\lambda\frac{3}{2}^-}$	2935	2871	2921	?
$1^4P_{\lambda\frac{1}{2}^-}$	2854	···	2900	?
$1^4P_{\lambda\frac{3}{2}^-}$	2912	···	2932	?
$1^4P_{\lambda\frac{5}{2}^-}$	2929	2905	2927	?
$1^2D_{\lambda\lambda\frac{3}{2}^+}$	3167	···	3089	?
$1^2D_{\lambda\lambda\frac{5}{2}^+}$	3166	···	3091	?
$1^4D_{\lambda\lambda\frac{1}{2}^+}$	3163	···	3075	?
$1^4D_{\lambda\lambda\frac{3}{2}^+}$	3160	···	3081	?
$1^4D_{\lambda\lambda\frac{5}{2}^+}$	3153	3080	3077	?
$1^4D_{\lambda\lambda\frac{7}{2}^+}$	3147	3094	3078	?

PRD107,034031 (2023)

Only the ground states are well established!

Decay properties of the λ mode P-wave Ξ'_c states

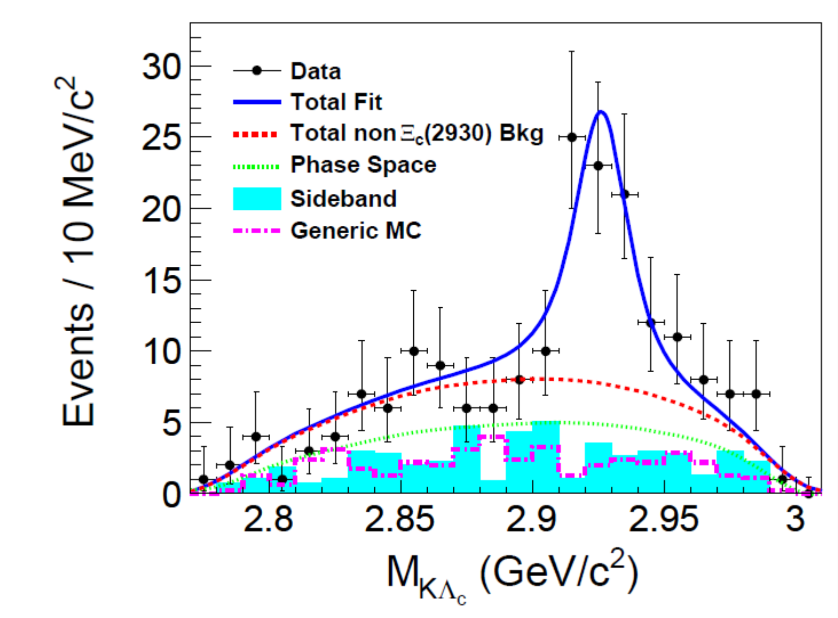
$\vert {}^{2S+1}L_\lambda J^P\rangle$	State	Channel	Γ_i (MeV)	$\mathcal{B}_i$
$\vert {}^2P_{\lambda}\frac{1}{2}^-\rangle$	$\Xi'_c(2936)$	$\Lambda_c K$	7.11	32.81%
		$\Xi_c\pi$	3.90	18.00%
		$\Xi'_c(2580)\pi$	10.08	46.52%
		$\Xi'_c(2645)\pi$	0.58	2.68%
		total	21.67	
$\vert {}^2P_{\lambda}\frac{3}{2}^-\rangle$	$\Xi'_c(2935)$	$\Lambda_c K$	3.73	17.86%
		$\Xi_c\pi$	10.85	51.94%
		$\Xi'_c(2580)\pi$	3.89	18.62%
		$\Xi'_c(2645)\pi$	2.42	11.58%
		total	20.89	
$\vert {}^4P_{\lambda}\frac{1}{2}^-\rangle$	$\Xi'_c(2854)$	$\Lambda_c K$	18.56	50.09%
		$\Xi_c\pi$	15.02	40.54%
		$\Xi'_c(2580)\pi$	3.44	9.28%
		$\Xi'_c(2645)\pi$	0.03	0.07
		total	37.05	
$\vert {}^4P_{\lambda}\frac{3}{2}^-\rangle$	$\Xi'_c(2912)$	$\Lambda_c K$	0.50	4.06%
		$\Xi_c\pi$	1.70	13.79%
		$\Xi'_c(2580)\pi$	0.13	1.05%
		$\Xi'_c(2645)\pi$	10.00	81.10%
		total	12.33	
$\vert {}^4P_{\lambda}\frac{5}{2}^-\rangle$	$\Xi'_c(2929)$	$\Lambda_c K$	4.06	20.10%
		$\Xi_c\pi$	12.24	60.59%
		$\Xi'_c(2580)\pi$	1.06	5.25%
		$\Xi'_c(2645)\pi$	2.84	14.06%
		total	20.2	

Relatively narrow states!

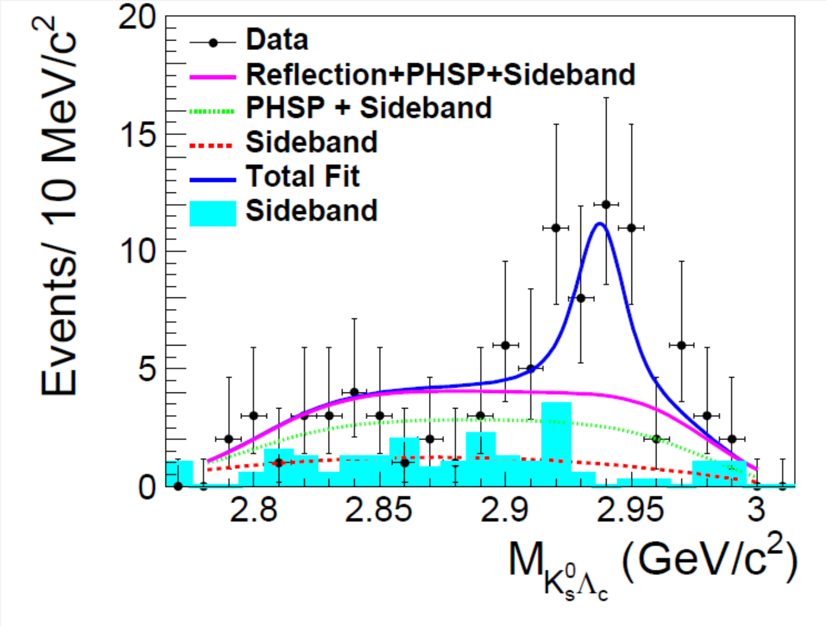
KL Wang, YX Yao, XH, QZ, PRD96,116016(2017)

Belle observed P-wave candidates $\Xi_c(2930,2940)$

YB Li et al, EPJC 78 (2018), 252



YB Li et al, EPJC 78 (2018), 928



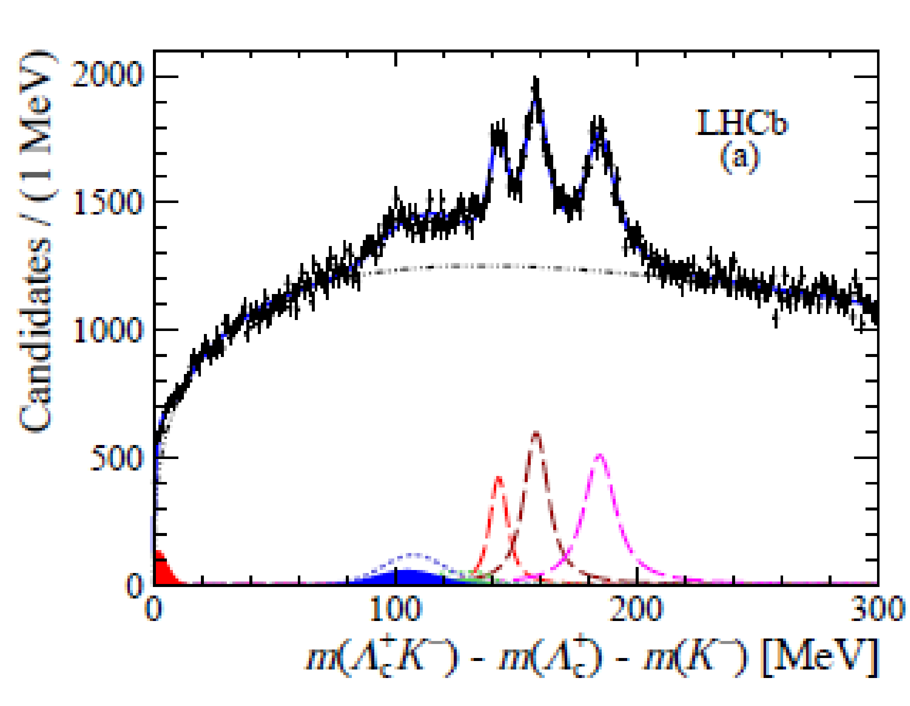
Mass: about 2929 MeV
Width: about 20 MeV

Mass: about 2942 MeV
Width: about 15 MeV

Mass, and decay mode are consistent with P wave candidates.

LHCb observed three P-wave candidates $\Xi_c(2923)$, $\Xi_c(2939)$, $\Xi_c(2965)$

Phys.Rev.Lett. 124 (2020), 222001



$$m[\Xi_c(2923)^0] = 2923.04 \pm 0.59 \text{ MeV},$$
$$\Gamma[\Xi_c(2923)^0] = 7.1 \pm 2.6 \text{ MeV},$$
$$m[\Xi_c(2939)^0] = 2938.55 \pm 0.52 \text{ MeV},$$
$$\Gamma[\Xi_c(2939)^0] = 10.2 \pm 1.9 \text{ MeV},$$
$$m[\Xi_c(2965)^0] = 2964.88 \pm 0.54 \text{ MeV},$$
$$\Gamma[\Xi_c(2965)^0] = 14.1 \pm 2.2 \text{ MeV}.$$

Mass, and decay mode are consistent with P wave candidates.

Our explaination with P wave Ξ'_c states

State	Mass	$\Gamma[\Xi_c\pi]$	$\Gamma[\Xi'_c\pi]$	$\Gamma[\Xi^*_c\pi]$	$\Gamma[\Lambda_c K]$	Γ^{th}_{total}	Γ^{exp}_{total}	Possible assignment
$\lvert 1P_{\lambda\frac{1}{2}^-}\rangle_1$	2880	0.86	12.9	0.18	1.17	15.1	$\cdots$	$\cdots$
$\lvert 1P_{\lambda\frac{1}{2}^-}\rangle_2$	2880	21.7	0.51	0.01	29.6	51.8	$\cdots$	$\cdots$
$\lvert 1^4P_{\lambda\frac{3}{2}^-}\rangle$	2923	1.74	0.15	10.7	0.48	13.1	$7.1 \pm 0.8 \pm 1.8$	$\Xi_c(2923)^0$
$\lvert 1^2P_{\lambda\frac{3}{2}^-}\rangle$	2939	10.2	3.80	2.46	3.74	20.2	$10.2 \pm 0.8 \pm 1.1$	$\Xi_c(2939)^0$
$\lvert 1^4P_{\lambda\frac{5}{2}^-}\rangle$	2965	15.5	1.64	3.57	5.43	26.1	$14.1 \pm 0.9 \pm 1.3$	$\Xi_c(2965)^0$

- $\Xi_c(2923)$, $\Xi_c(2939)$ may correspond to two $J^P=3/2^-$ states.
- $\Xi_c(2965)$ may be the $J^P=5/2^-$ state.
- To confirm the nature, the other dominant decay modes should be further observed.

Kai-Lei Wang, Li-Ye Xiao, XH, PRD102,034029 (2020)

Evidence a new P-wave state $\Xi_c(2880)$ at LHCb

Phys.Rev.D 108 (2023), 012020

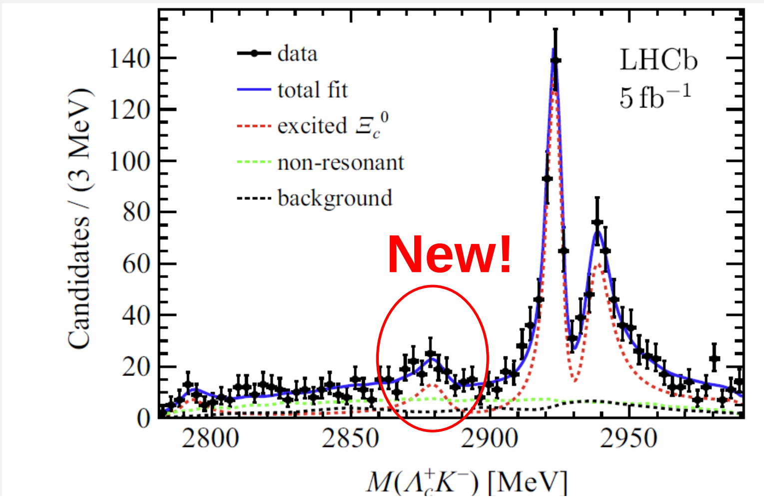
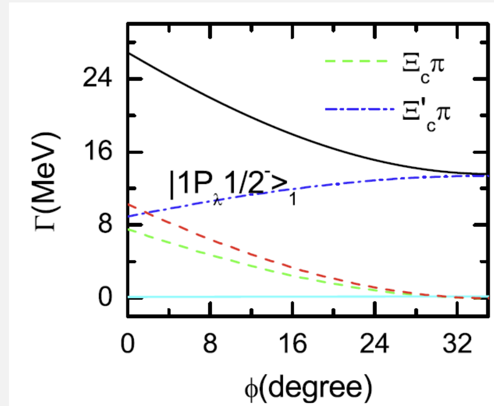
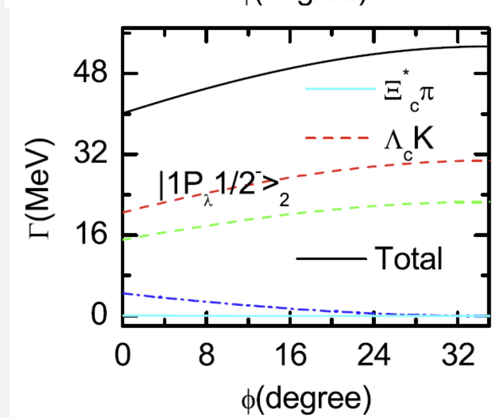


TABLE II. Measured masses, widths and significance of excited Ξ_c^0 states.

State	Mass (MeV)	Width (MeV)	Significance
$\Xi_c(2880)^0$	$2881.8 \pm 3.1 \pm 8.5$	$12.4 \pm 5.2 \pm 5.8$	3.8σ
$\Xi_c(2923)^0$	$2924.5 \pm 0.4 \pm 1.1$	$4.8 \pm 0.9 \pm 1.5$	$>10\sigma$
$\Xi_c(2939)^0$	$2938.5 \pm 0.9 \pm 2.3$	$11.0 \pm 1.9 \pm 7.5$	$>10\sigma$



Narrow state

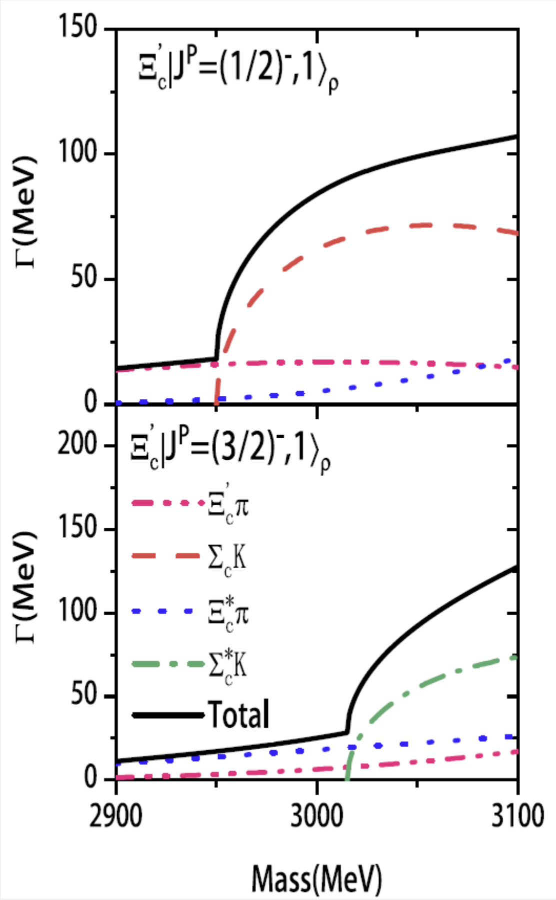


Broad state

KL Wang, LY Xiao, XH, PRD102,034029（2020）

Mass, and decay mode are consistent with a narrow P wave candidate with JP=1/2-.

Can find ρ mode P-wave states?



States	Decay modes				
	$\Xi_c'\pi$	$\Xi_c^*\pi$	$\Sigma_c K$	$\Sigma_c^* K$	Total
$\Xi_c'\lvert J^P=\frac{1}{2}^-,1\rangle_\rho(3060)$	16.3	11.7	71.7	1.1	100.8
$\Xi_c'\lvert J^P=\frac{3}{2}^-,1\rangle_\rho(3096)$	16.4	25.8	10.4	72.8	125.4

There two ρ mode states with JP=1/2- and 3/2-,respectively. The mass is about 3.1 GeV. The decay width is about 100 MeV.

Wen-Jia Wang, Li-Ye Xiao, XH, PRD106,074020（2022)

Puzzle on Ξ_c(2970)

Citation: S. Navas *et al.* (Particle Data Group), Phys. Rev. D **110**, 030001 (2024)

$\boxed{\Xi_c(2970)}$ $\quad I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ∗∗∗

was $\Xi_c(2980)$

$J^P = 1/2^+$ is favored by MOON 21.

Γ_1	$\Lambda_c^+ \overline{K} \pi$	seen
Γ_2	$\Sigma_c(2455) \overline{K}$	seen
Γ_3	$\Lambda_c^+ \overline{K}$	not seen
Γ_4	$\Lambda_c^+ K^-$	seen
Γ_5	$\Xi_c 2\pi$	seen
Γ_6	$\Xi'_c \pi$	seen
Γ_7	$\Xi_c(2645) \pi$	seen

As a 2S or 1D state with JP=1/2+,

The mass is hard to understand

The decay properties is hard to understand

Ξ_c(2965) observed at LHCb may be different from that observed at Belle and Babar.

Decay properties of the D-wave Ξ'_c states

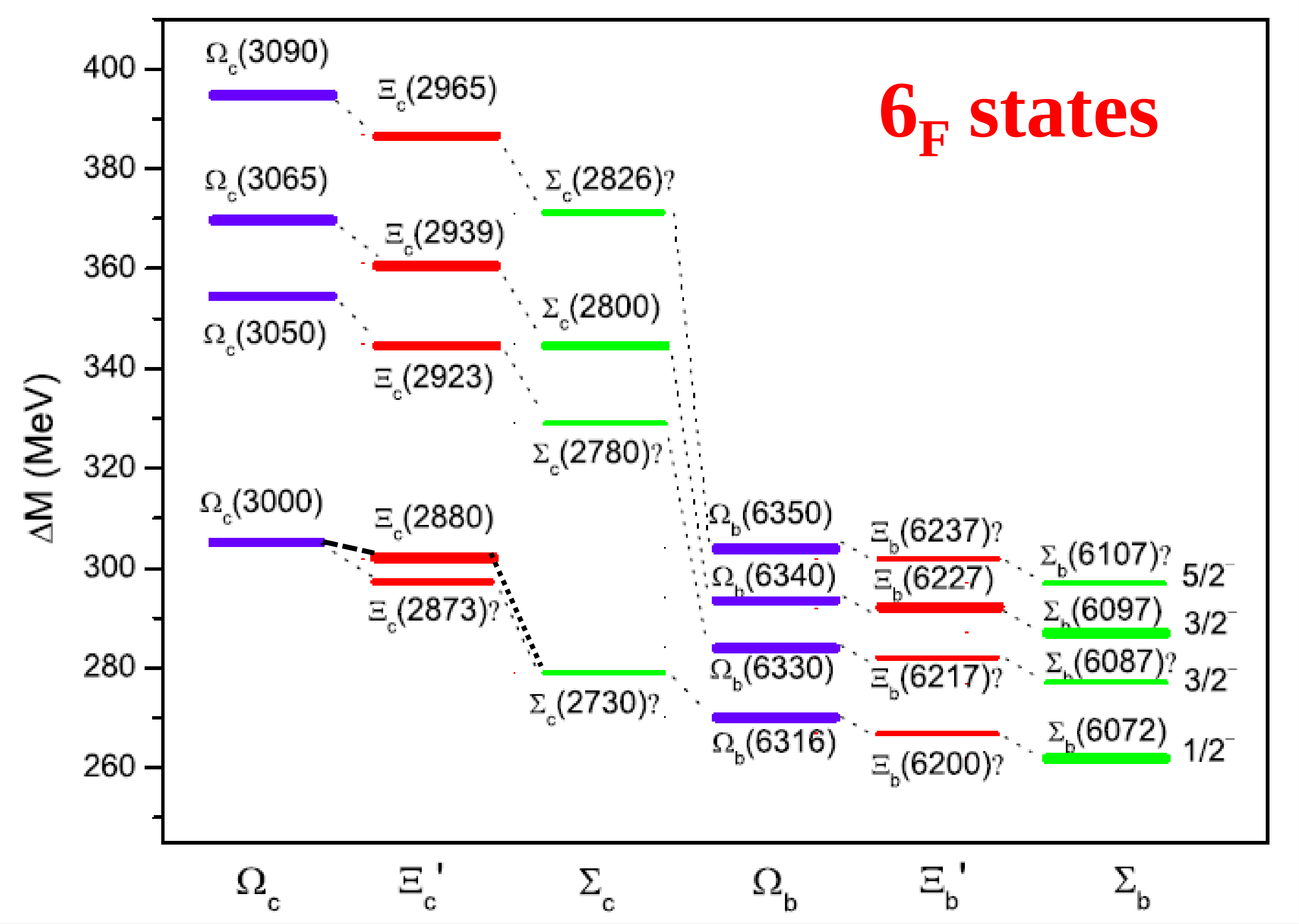
Decay mode	M_f	$\vert\Xi_c'\,^2D_{\lambda\lambda\frac{3}{2}^+}\rangle(3167)$ Γ_i (MeV)	$\vert\Xi_c'\,^2D_{\lambda\lambda\frac{5}{2}^+}\rangle(3166)$ Γ_i (MeV)	$\vert\Xi_c'\,^4D_{\lambda\lambda\frac{1}{2}^+}\rangle(3163)$ Γ_i (MeV)	$\vert\Xi_c'\,^4D_{\lambda\lambda\frac{3}{2}^+}\rangle(3160)$ Γ_i (MeV)	$\vert\Xi_c'\,^4D_{\lambda\lambda\frac{5}{2}^+}\rangle(3153)$ Γ_i (MeV)	$\vert\Xi_c'\,^4D_{\lambda\lambda\frac{7}{2}^+}\rangle(3147)$ Γ_i (MeV)
$\Xi_c\pi$	2470	$2.43^{+2.13}_{-1.59}$	$5.13^{-0.96}_{+1.05}$	$4.92^{+4.18}_{-3.19}$	$2.48^{+2.06}_{-1.60}$	$1.32^{-0.25}_{+0.29}$	$5.68^{-1.10}_{+1.24}$
$\Xi_c'\pi$	2578	$3.51^{+1.79}_{-1.66}$	$2.77^{-0.62}_{+0.77}$	$1.75^{+0.88}_{-0.81}$	$0.87^{+0.44}_{-0.40}$	$0.17^{-0.03}_{+0.05}$	$0.73^{-0.17}_{+0.21}$
$\Xi_c'^*\pi$	2645	$0.74^{-0.09}_{+0.13}$	$1.18^{+0.27}_{-0.26}$	$0.76^{+0.27}_{-0.28}$	$2.94^{+0.72}_{-0.69}$	$4.28^{+0.34}_{-0.24}$	$0.56^{+0.06}_{-0.04}$
$\Lambda_c K$	2286	$1.23^{+1.13}_{-0.83}$	$1.25^{-0.43}_{+0.53}$	$2.51^{+2.24}_{-1.67}$	$1.27^{+1.12}_{-0.84}$	$0.72^{-0.13}_{+0.15}$	$3.09^{-0.58}_{+0.63}$
$\Sigma_c K$	2455	$6.37^{+1.97}_{-2.07}$	$1.72^{-0.43}_{+0.58}$	$3.16^{+0.96}_{-1.0}$	$1.57^{+0.46}_{-0.49}$	$0.11^{-0.03}_{+0.04}$	$0.40^{-0.10}_{+0.14}$
$\Sigma_c^* K$	2520	$0.47^{-0.01}_{+0.04}$	$1.57^{+0.25}_{-0.28}$	$1.22^{+0.23}_{-0.26}$	$3.97^{+0.62}_{-0.70}$	$4.18^{+0.37}_{-0.40}$	$0.59^{+0.08}_{-0.08}$
$\vert\Lambda_c\,^2P_{\lambda\frac{1}{2}^-}\rangle K$	2592	$0.84^{+0.11}_{-0.10}$	$0.55^{+0.08}_{-0.06}$	$3.66^{-0.30}_{+0.38}$	$3.55^{+1.22}_{-1.06}$	$0.65^{-0.05}_{+0.07}$	$10.1^{+2.5}_{-2.3}$
$\vert\Lambda_c\,^2P_{\lambda\frac{3}{2}^-}\rangle K$	2628	$10.9^{+2.4}_{-2.1}$	$0.24^{+0.10}_{-0.05}$	$39.1^{+9.5}_{-8.6}$	$7.25^{+1.53}_{-1.36}$	$0.15^{+0.02}_{-0.02}$	$1.15^{+0.15}_{-0.13}$
$\vert\Xi_c\,^2P_{\lambda\frac{1}{2}^-}\rangle\pi$	2792	$1.85^{+0.15}_{-0.13}$	$1.83^{+0.15}_{-0.13}$	$14.5^{-1.28}_{+2.11}$	$9.28^{+1.53}_{-1.43}$	$3.37^{-0.31}_{+0.36}$	$14.4^{+4.0}_{-3.5}$
$\vert\Xi_c\,^2P_{\lambda\frac{3}{2}^-}\rangle\pi$	2815	$47.3^{+7.7}_{-7.3}$	$3.54^{-0.82}_{+1.13}$	$40.2^{+11.9}_{-10.5}$	$11.8^{+1.7}_{-1.4}$	$0.67^{+0.03}_{-0.02}$	$8.81^{+0.04}_{-0.04}$
$\vert\Xi_c'\,^2P_{\lambda\frac{1}{2}^-}\rangle\pi$	2936	$0.39^{+0.05}_{-0.05}$	$0.21^{-0.03}_{+0.04}$	$0.26^{-0.03}_{<+0.01}$	$0.51^{+0.15}_{-0.14}$	0.03	$0.92^{+0.21}_{-0.19}$
$\vert\Xi_c'\,^2P_{\lambda\frac{3}{2}^-}\rangle\pi$	2935	$8.53^{+1.70}_{-1.50}$	$0.22^{-0.03}_{+0.04}$	$5.50^{+1.33}_{-1.21}$	$1.0^{+0.13}_{-0.11}$	< 0.01	$0.33^{+0.02}_{-0.02}$
$\vert\Xi_c'\,^4P_{\lambda\frac{1}{2}^-}\rangle\pi$	2854	$0.23^{-0.07}_{+0.10}$	$1.00^{+0.32}_{-0.30}$	$0.75^{-0.11}_{+0.14}$	$20.5^{+2.9}_{-2.6}$	$13.0^{+2.1}_{-2.0}$	< 0.01
$\vert\Xi_c'\,^4P_{\lambda\frac{3}{2}^-}\rangle\pi$	2912	$1.01^{+0.10}_{-0.07}$	$0.41^{+0.04}_{-0.04}$	$1.10^{+0.03}_{-0.02}$	$5.62^{+0.82}_{-0.72}$	$2.85^{+1.08}_{-0.94}$	$0.34^{<-0.01}_{<+0.01}$
$\vert\Xi_c'\,^4P_{\lambda\frac{5}{2}^-}\rangle\pi$	2929	$0.59^{+0.04}_{-0.02}$	$1.46^{+0.22}_{-0.18}$	$2.23^{+0.64}_{-0.57}$	$5.75^{+1.51}_{-1.35}$	$7.55^{+1.17}_{-1.05}$	$0.37^{<-0.01}_{+0.01}$
Sum		$86.4^{+19.1}_{-17.2}$	$23.1^{-1.9}_{+2.8}$	$121.6^{+30.4}_{-25.5}$	$78.4^{+16.9}_{-14.9}$	$39.1^{+4.3}_{-3.7}$	$47.5^{+5.1}_{-4.1}$

Broader than the P wave states.

The $J^P=5/2^+$ and $7/2^+$ states are worth observing!

YX Yao, KL Wang, XH, PRD98,076015(2018)

Summary for 6_F states



结束语

LHCb,Belle II为我们研究重味重子谱带来机遇！

许多夸克模型预言的态值得实验寻找。

谢谢！