Spectroscopy of charm baryons at LHCb

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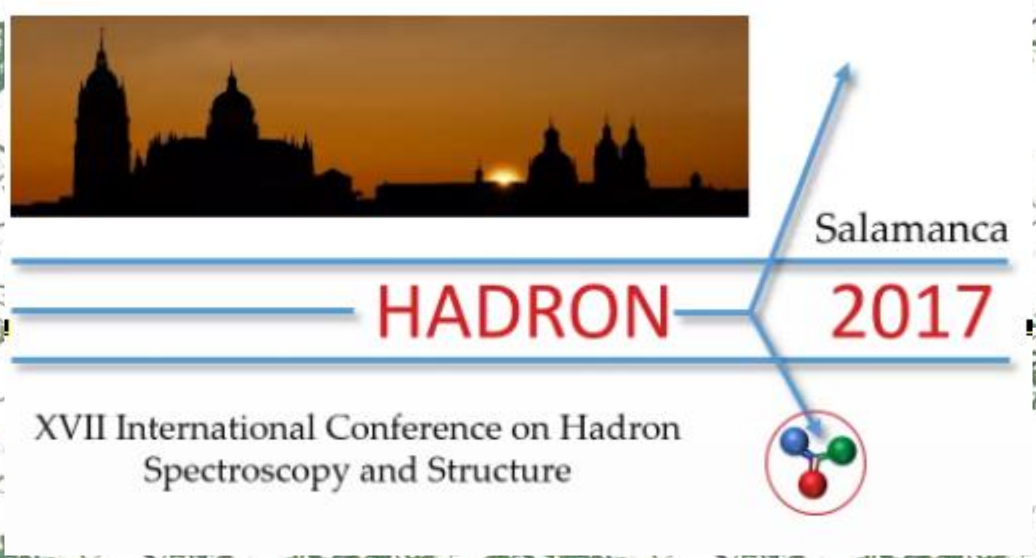
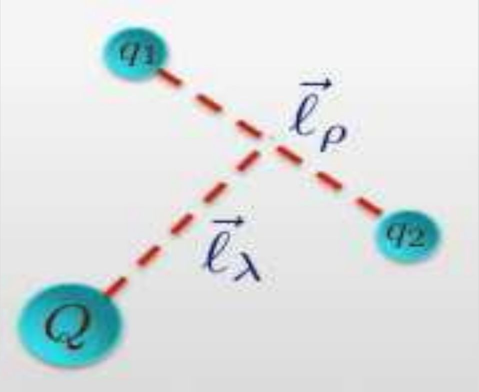
on behalf of LHCb collaboration



29.09.2k+17

Charm baryons

- Interesting spectroscopy:
  - Three quarks **cq_1q_2**, many degrees of freedom
    - Some lack of experimental data
- Frequently used approach
  - Light diquark **q_1q_2** + heavy **c**-quark

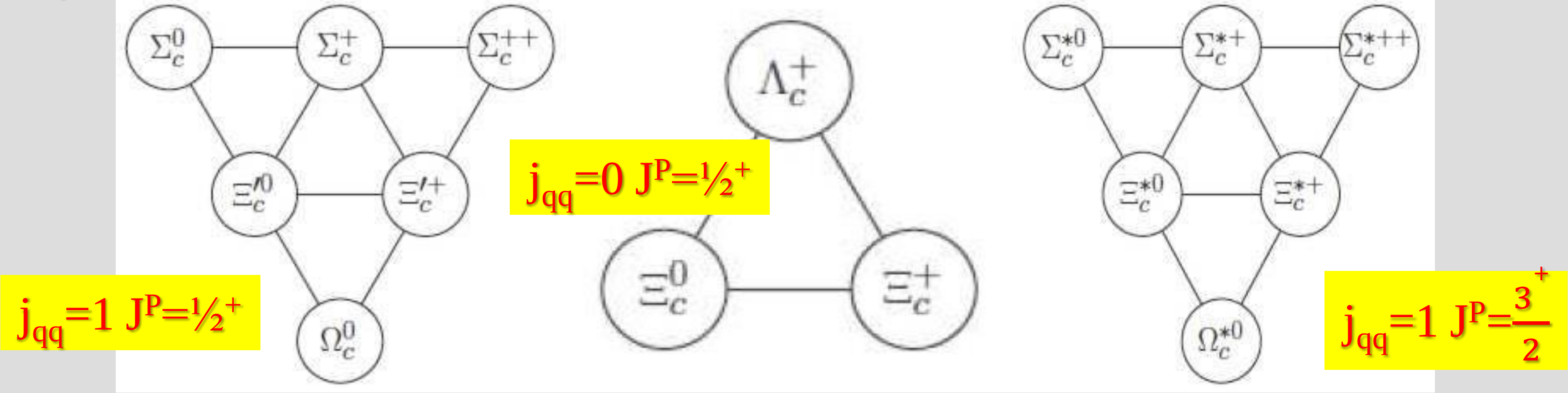


  - Scalar **q_1q_2**-diquark
    - The most «simple» hadrons
  - Light **q_1q_2**-diquark
    - HQET – very successful approach

What to do with non-scalar diqark? How to treat not so light diquark?

cq_1q_2 baryons

- Ground states: spin of light diquark j_{qq}, spin-parity of baryon J^P



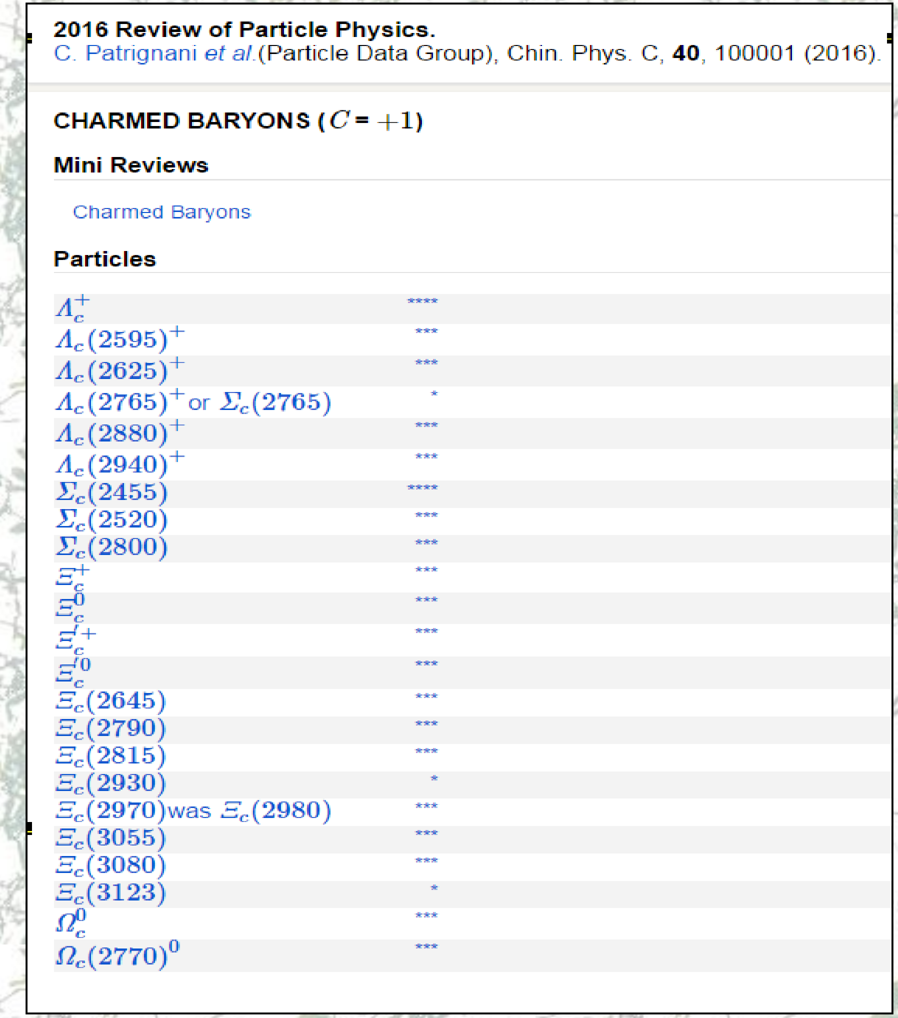
$j_{qq}=1\ J^P=½^+$

$j_{qq}=0\ J^P=½^+$

$j_{qq}=1\ J^P=\frac{3}{2}^+$

- All ground states are observed
  - ☺ Precise measurements of masses and lifetimes
  - ☹ Quantum numbers are not measured explicitely

Excited states



2016 Review of Particle Physics.
C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016).

CHARMED BARYONS ($C = +1$)

Mini Reviews

Charmed Baryons

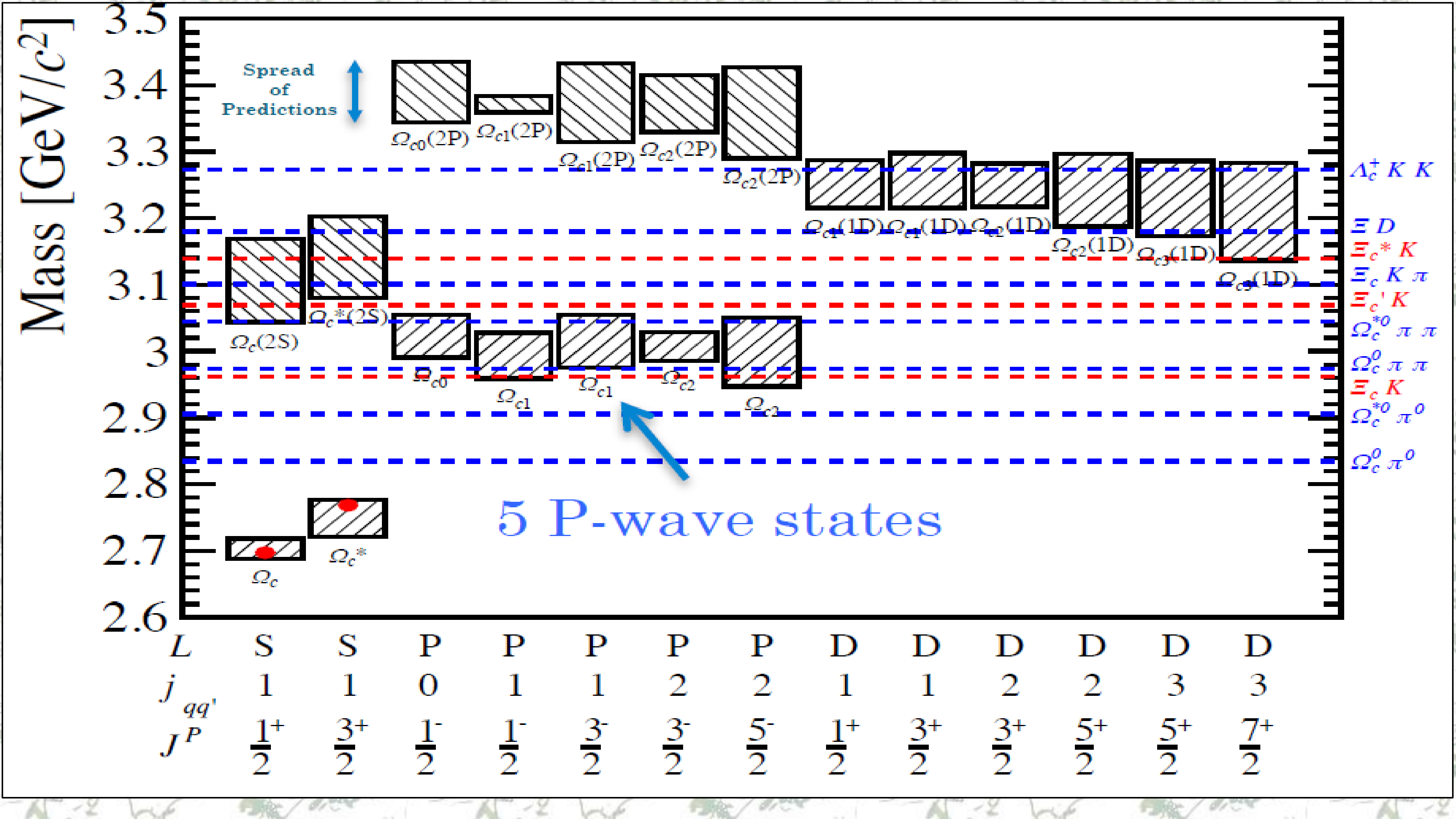
Particles

Λ_c^+	****
$\Lambda_c(2595)^+$	***
$\Lambda_c(2625)^+$	***
$\Lambda_c(2765)^+$ or $\Sigma_c(2765)$	*
$\Lambda_c(2880)^+$	***
$\Lambda_c(2940)^+$	***
$\Sigma_c(2455)$	****
$\Sigma_c(2520)$	***
$\Sigma_c(2800)$	***
Ξ_c^+	***
Ξ_c^0	***
$\Xi_c'^+$	***
$\Xi_c'^0$	***
$\Xi_c(2645)$	***
$\Xi_c(2790)$	***
$\Xi_c(2815)$	***
$\Xi_c(2930)$	*
$\Xi_c(2970)$ was $\Xi_c(2980)$	***
$\Xi_c(3055)$	***
$\Xi_c(3080)$	***
$\Xi_c(3123)$	*
Ω_c^0	***
$\Omega_c(2770)^0$	***

- PDG-2016:
  - No experimental data for excited Ω_c states
- ☹ relatively small production cross-sections
  - Both in e^+e^- and in hadron collisions
  - Small $B(b \to \Omega_c X)$

Rich phenomenology, many predictions

Several theory approaches, many predictions

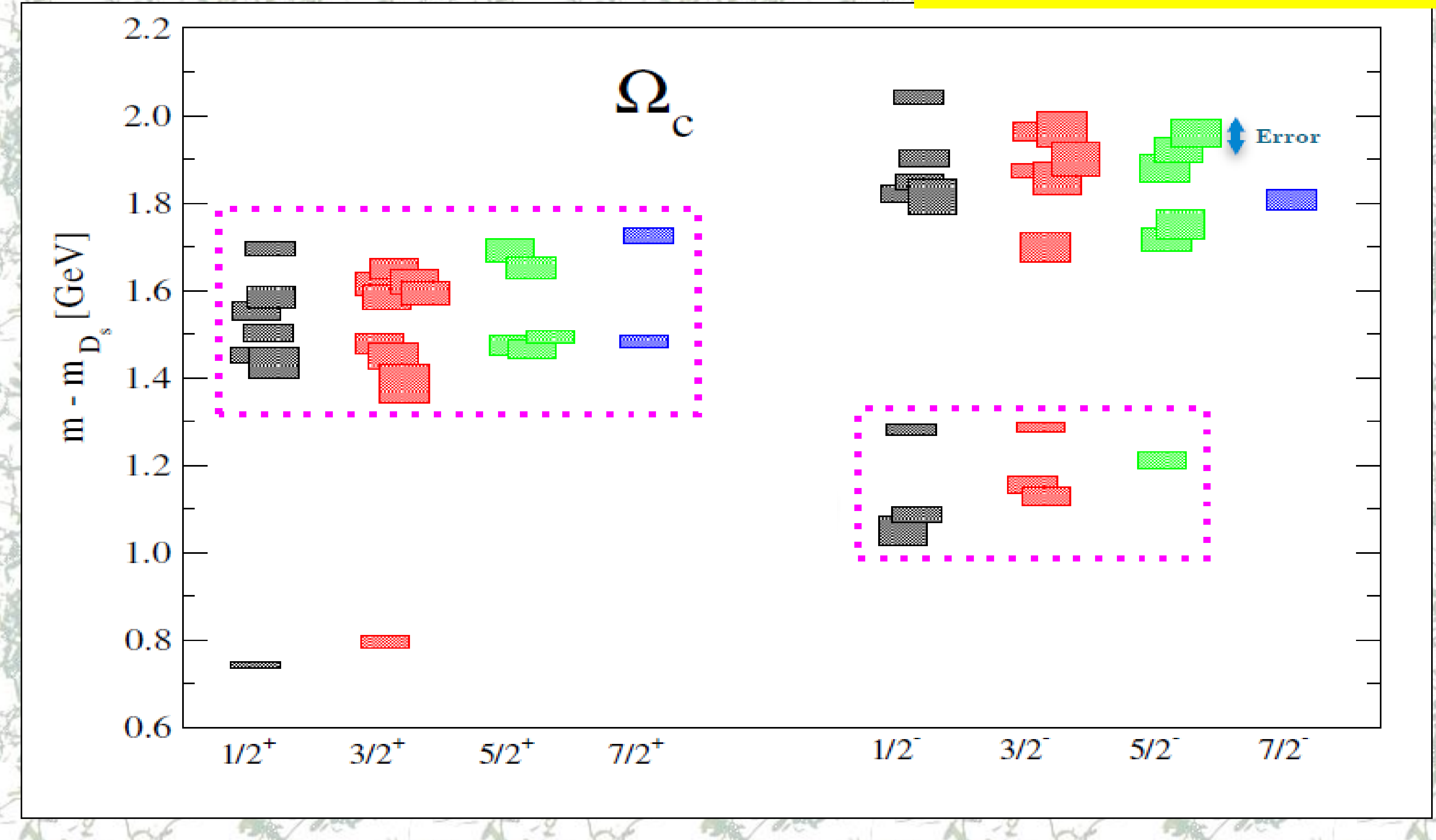


Spread of Predictions

5 P-wave states

Lattice QCD

M. Padmanath *et al.* `arXiv:1311.4806`



$\Xi_c \to pK^-\pi^+$

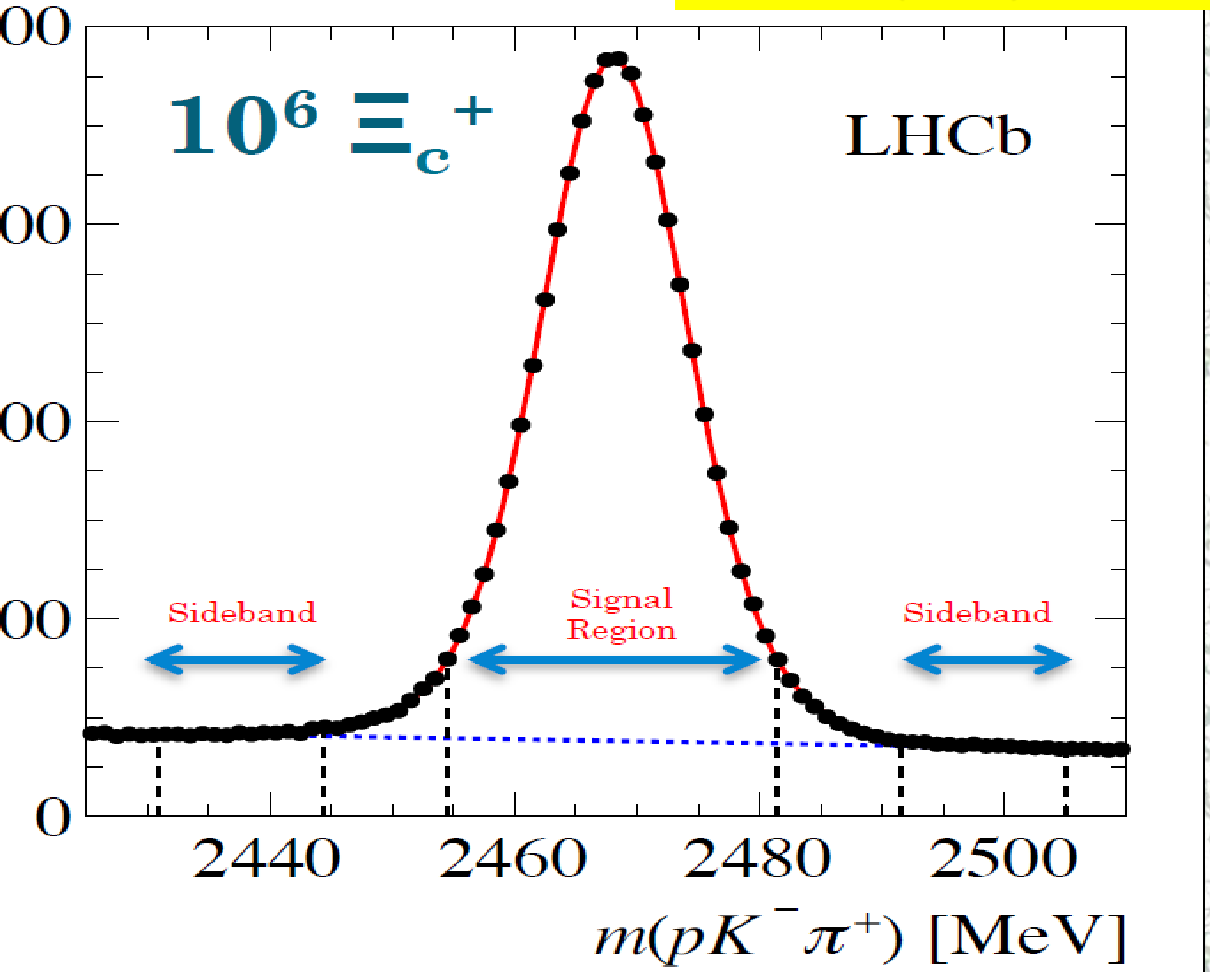
PRL 118(2017) 182001

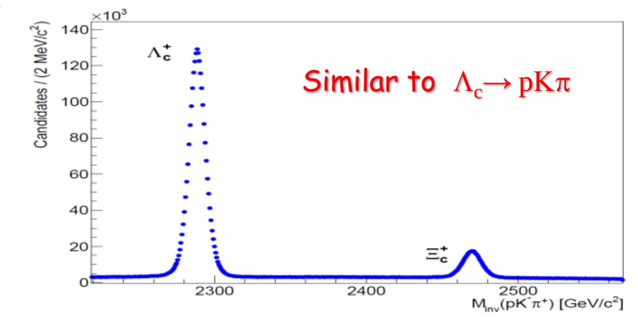
Simple topology

3-body secondary vertex

Cabibbo-suppressed decay

- Proton ID
- Kaon ID
- Vertex quality, …
- Lifetime, …
- …





Similar to $\Lambda_c \to pK\pi$

$\Xi_c^+K^-$ spectrum

+add well-identified kaon from the primary vertex

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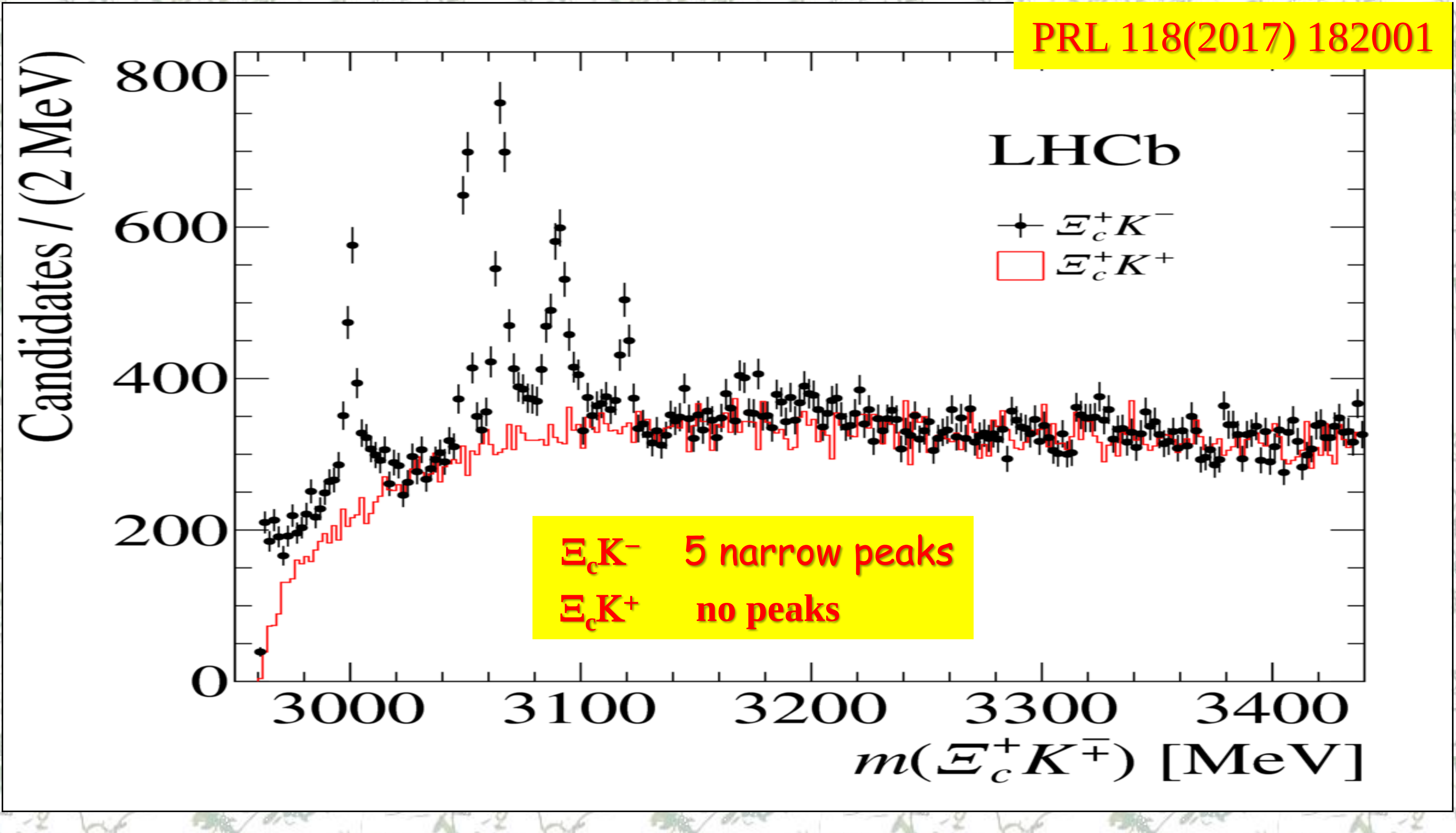

Ξ_cK^- 5 narrow peaks

Ξ_cK^+ no peaks

$\Xi_c^+K^-$ spectrum

$(\Xi_c^{'+} \to \Xi_c\gamma)\ K^-$ threshold

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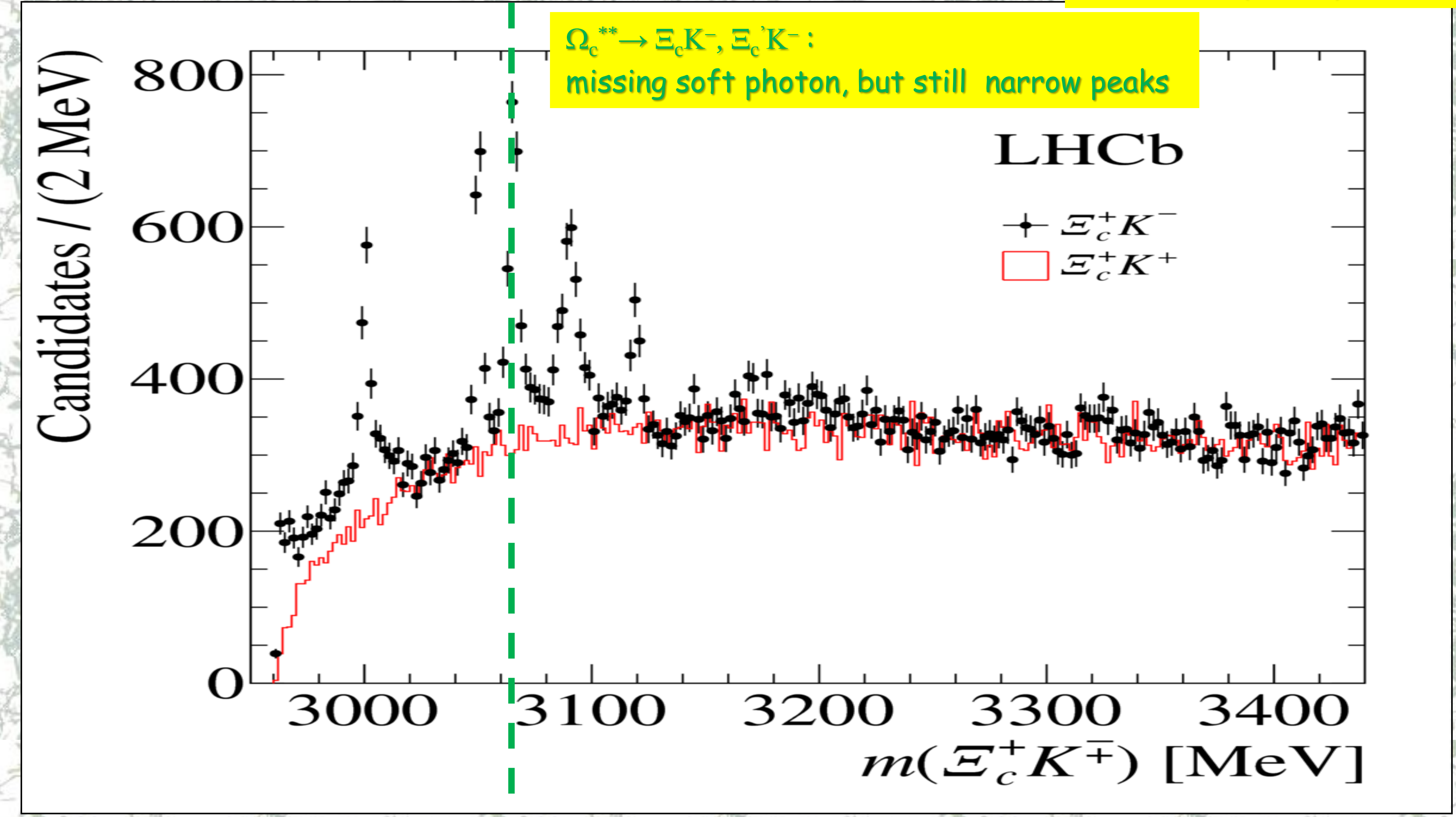

$\Omega_c^{**} \to \Xi_cK^-, \Xi_c^{'}K^-$:
missing soft photon, but still narrow peaks

Fit model

6 RBW*G, resolution: 0.7-1.7MeV/c^2

+3 components for Ξ_c'K

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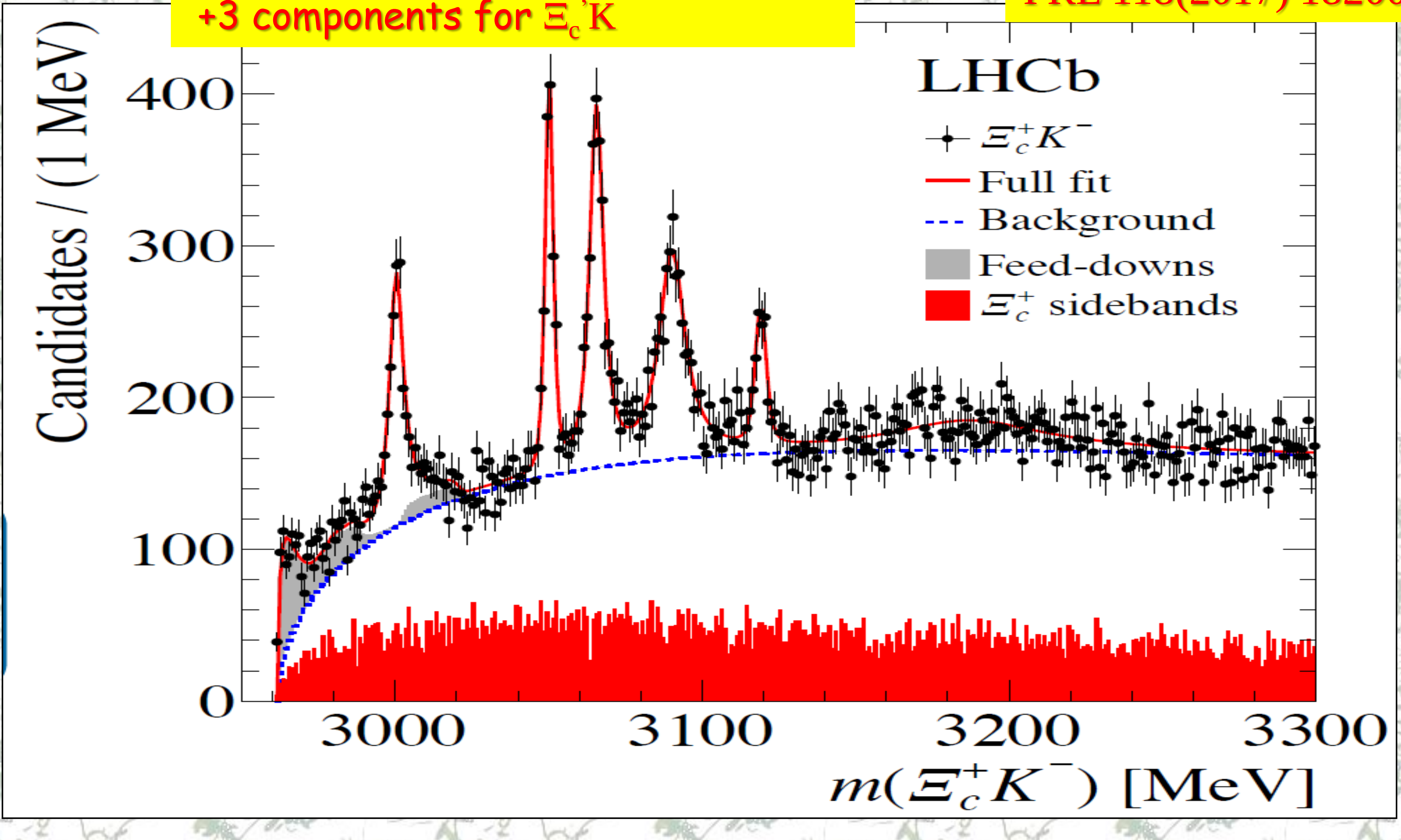
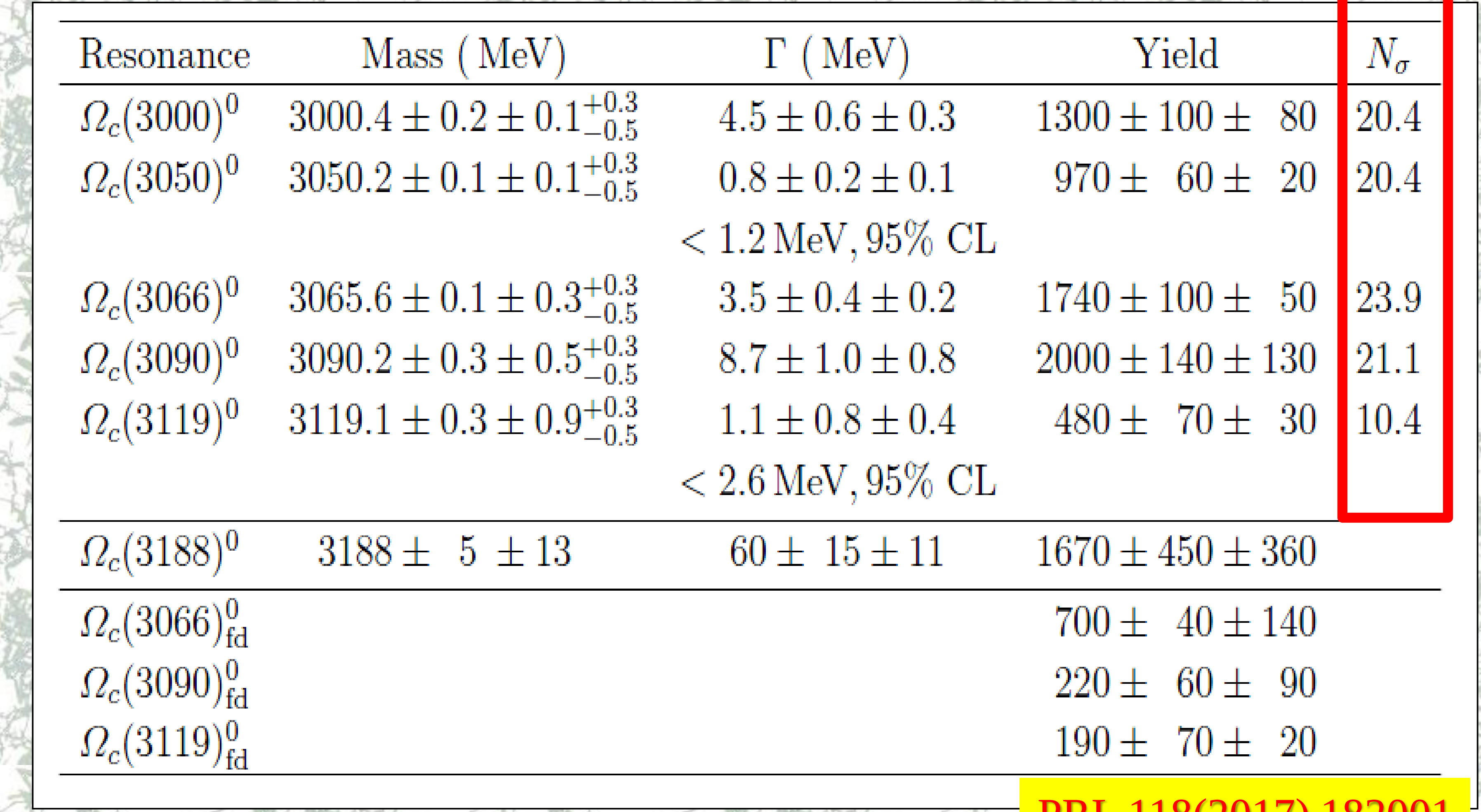


Results



Resonance	Mass (MeV)	Γ (MeV)	Yield	N_σ
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	$1300 \pm 100 \pm 80$	20.4
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$	$970 \pm 60 \pm 20$	20.4
		$< 1.2\,\text{MeV}, 95\%\ \text{CL}$		
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	$1740 \pm 100 \pm 50$	23.9
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	$2000 \pm 140 \pm 130$	21.1
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$	$480 \pm 70 \pm 30$	10.4
		$< 2.6\,\text{MeV}, 95\%\ \text{CL}$		
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$	$1670 \pm 450 \pm 360$	
$\Omega_c(3066)^0_{\text{fd}}$			$700 \pm 40 \pm 140$	
$\Omega_c(3090)^0_{\text{fd}}$			$220 \pm 60 \pm 90$	
$\Omega_c(3119)^0_{\text{fd}}$			$190 \pm 70 \pm 20$	

PRL 118(2017) 182001

What are they?

Wang *et al*, PRD95(2017)116019

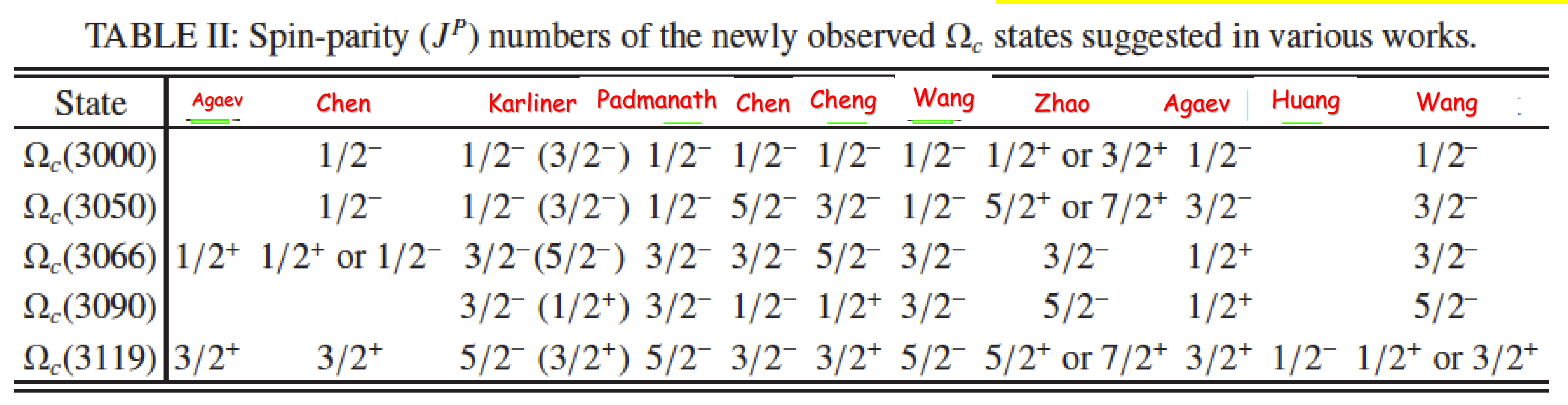


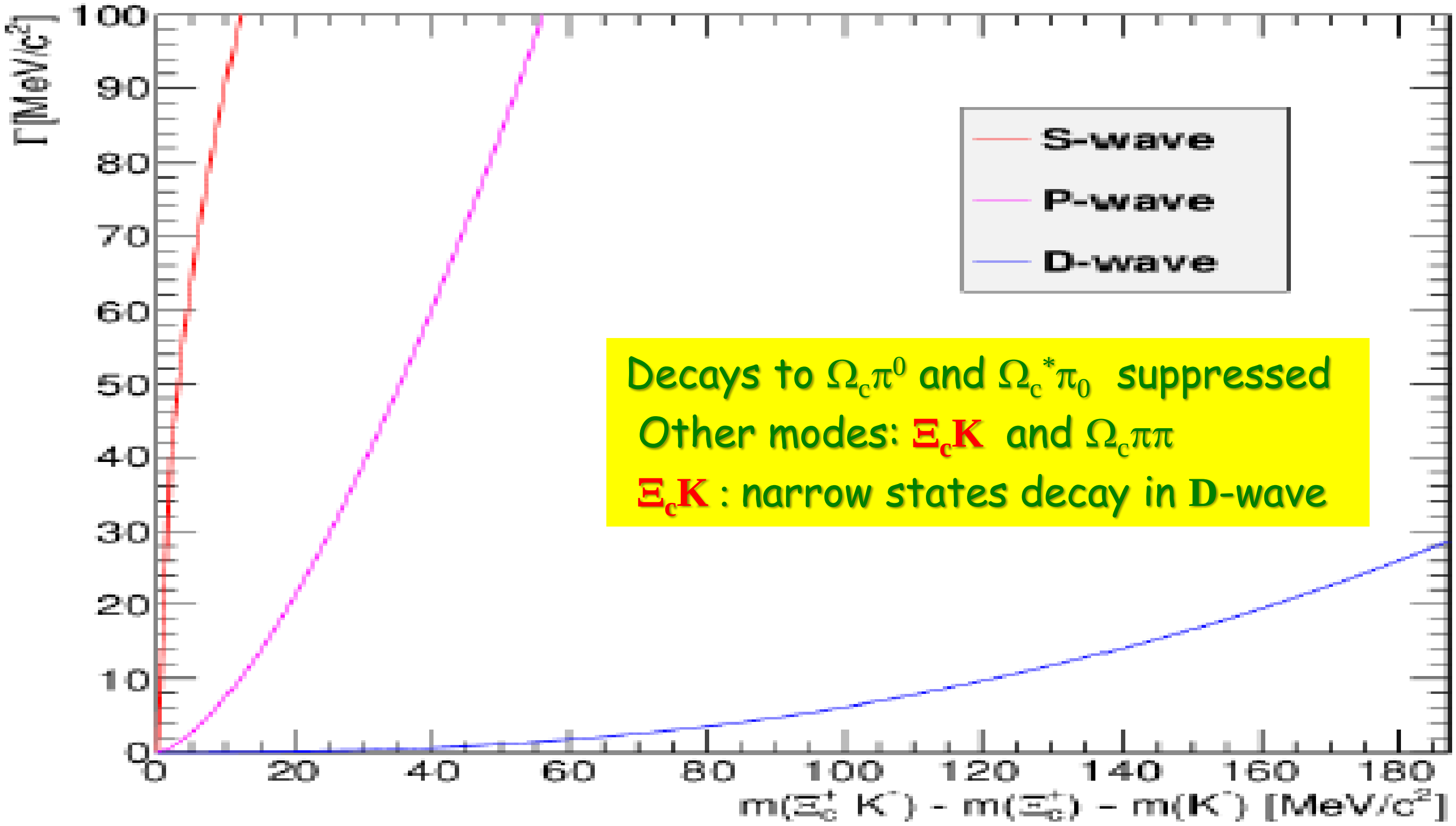
TABLE II: Spin-parity (J^P) numbers of the newly observed Ω_c states suggested in various works.

State	Agaev	Chen	Karliner	Padmanath	Chen	Cheng	Wang	Zhao	Agaev	Huang	Wang
$\Omega_c(3000)$		$1/2^-$	$1/2^-$ $(3/2^-)$	$1/2^-$	$1/2^-$	$1/2^-$	$1/2^-$	$1/2^+$ or $3/2^+$	$1/2^-$		$1/2^-$
$\Omega_c(3050)$		$1/2^-$	$1/2^-$ $(3/2^-)$	$1/2^-$	$5/2^-$	$3/2^-$	$1/2^-$	$5/2^+$ or $7/2^+$	$3/2^-$		$3/2^-$
$\Omega_c(3066)$	$1/2^+$	$1/2^+$ or $1/2^-$	$3/2^-$$(5/2^-)$	$3/2^-$	$3/2^-$	$5/2^-$	$3/2^-$	$3/2^-$	$1/2^+$		$3/2^-$
$\Omega_c(3090)$			$3/2^-$ $(1/2^+)$	$3/2^-$	$1/2^-$	$1/2^+$	$3/2^-$	$5/2^-$	$1/2^+$		$5/2^-$
$\Omega_c(3119)$	$3/2^+$	$3/2^+$	$5/2^-$ $(3/2^+)$	$5/2^-$	$3/2^-$	$3/2^+$	$5/2^-$	$5/2^+$ or $7/2^+$	$3/2^+$	$1/2^-$	$1/2^+$ or $3/2^+$

- 5 orbitally excited states?
  - Why all 5 are narrow?
- 3 orbitally excited + 2 radial excitations?
  - Where are 2 “missing” orbital excitations?
- Pentaquarks?
  - ???

Why are they so narrow?

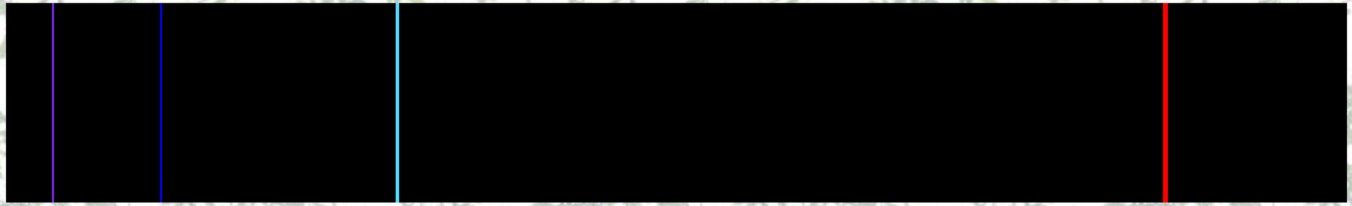
Why are they so narrow?



Decays to $\Omega_c\pi^0$ and $\Omega_c^*\pi_0$ suppressed

Other modes: **Ξ_cK** and $\Omega_c\pi\pi$

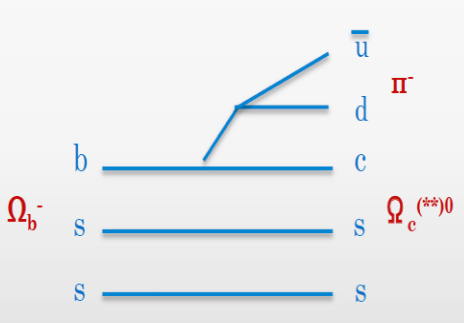
Ξ_cK : narrow states decay in **D**-wave

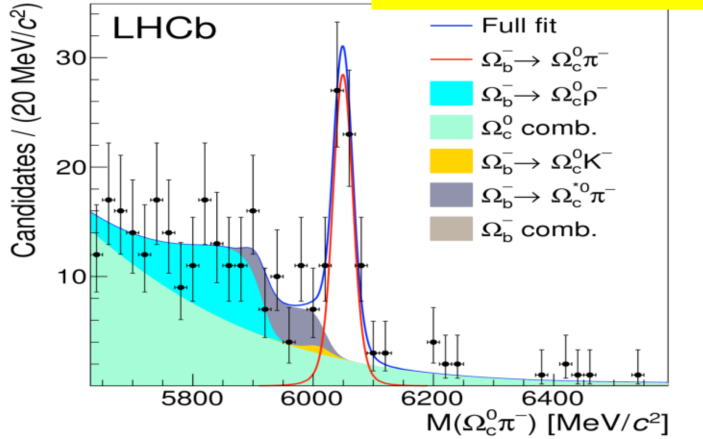


- 5 narrow states are observed
  - (+hint for possible wide state(s))
  - *2 of them are extremely narrow*
- (Unfortunately) quantum numbers are now know
- Most “popular” interpretation:
  - 5 P-wave states: $j_{ss}=1, L_{(ss)c}=1$
    - $2\times(1/2)^{-}$ $2\times(3/2)^{-}$ $1\times(5/2)^{-}$
- Other interpretations also possible
    - $2\times(3/2)^{-}$ $1\times(5/2)^{-}$ and (2S): $(1/2)^{+}$ $(3/2)^{+}$

Prospects: quantum numbers

- Fully reconstructed decays: $\Omega_b^- \to (\Xi_c^+ K^-)\,\pi^-$
  - Similar decay $\Omega_b^- \to (\Omega_c^0 \to pKK\pi)\,\pi^-$ is observed: the same quark diagram, the same number and type of tracks in final state





PRD93 (2016) 092007

  - With larger statistics determination of spin-parity of Ω_c^{**} resonances should be possible
    - proof & examples in the next (S.Neubert's) talk

Thank you!