LHCb Hadron Spectroscopy in Germany

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Hadron physics publications

Title	Citations
Observation of $J/\psi p$J/ψp resonances consistent with pentaquark states in $\Lambda 0b \to J/\psi K - p\Lambda$b0→J/ψK−p decays	455
Measurement of the ratio of branching fractions B($\bar{B}^{0} \to D^{*+}\tau^{-}\bar{\nu}_{\tau}$)/B($\bar{B}^{0} \to D^{*+}\mu^{-}\bar{\nu}_{\mu}$)	283
Observation of the rare Bs0→μ+μ− decay from the combined analysis of CMS and LHCb data	323
Test of lepton universality using $B+ \to K+\ell+\ell-$B+→K+ℓ+ℓ− decays	442
Determination of the X(3872) meson quantum numbers	266
Prompt charm production in pp collisions at $\sqrt{s}$ = 7 TeV	206
First Evidence for the Decay $B0s \to \mu+\mu-$	441
Strong constraints on the rare decays Bs0→μ+μ− and $B0 \to \mu+\mu-$	266
Evidence for CP violation in time-integrated $D0 \to h-h+$D0→h−h+ decay rates	328
Measurement of J/ψ production in pp collisions at $\sqrt{s}$ = 7 TeV	349
Measurement of σ(pp→bb¯X) at $\sqrt{s}$=7 TeV in the forward region	313
Observation of the resonant character of the Z(4430)− state	245

Strong German Hadron Spectroscopy Community

Experimental:

- COMPASS
- BES III
- PANDA
- MAMI
- CB-ELSA
- BELLE II
- LHCb

Focus on medium energy experiments

A lot of light-hadron phenomenology

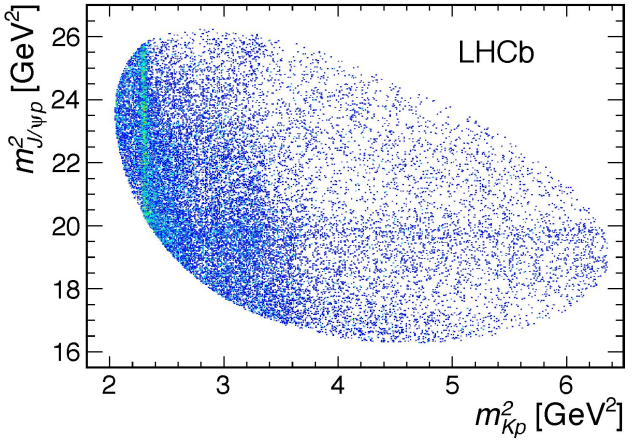
Light and hidden-charm exotics

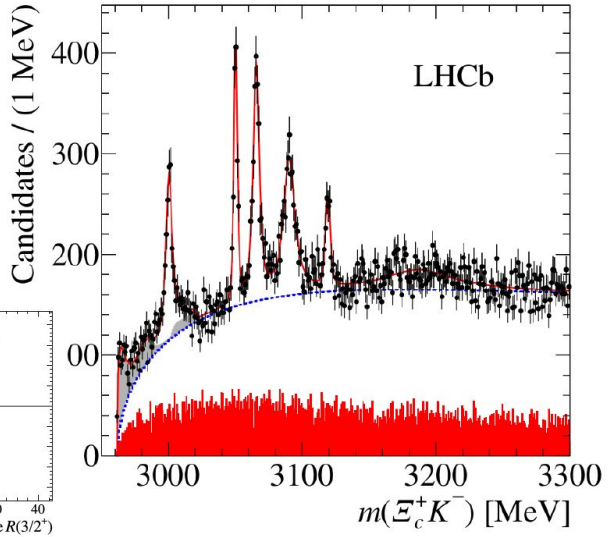
Theory Groups:

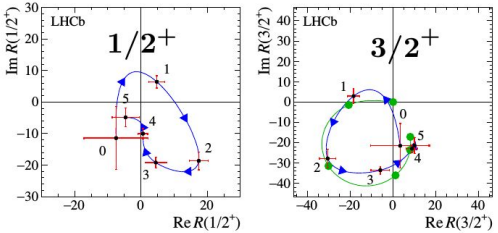
- Bonn
- Juelich
- GSI
- Giessen
- Siegen
- TUM
- ...

Hot Topics set by LHCb

- Pentaquark phenomenology
- Heavy baryon spectroscopy
  - Omega_c
  - Xi_cc
- Hidden charm exotic mesons
  - X(3872)
  - Z(4430)+
  - X(4140) and friends in J/psi Phi
  - More analyses in the pipeline
- Amplitude analysis techniques
  - Checking resonant character with model-independent parameterisations







What Role does LHCb see for itself in Spectroscopy?

- Still a niche topic in LHCb Germany
  - **S.N.: Pentaquarks**
  - Exotic mesons? E.g. Spin exotics
- LHCb currently has world-best data sets
  - More ideas than people to work on it
  - Try to attract more German collaborators?
- LHCb as a driver of analysis techniques
  - Requires close collaboration with phenomenology
  - Coupled channel analyses
  - Using constraints from other experiments (especially on light quark systems)
  - Open data / reinterpretation interfaces?

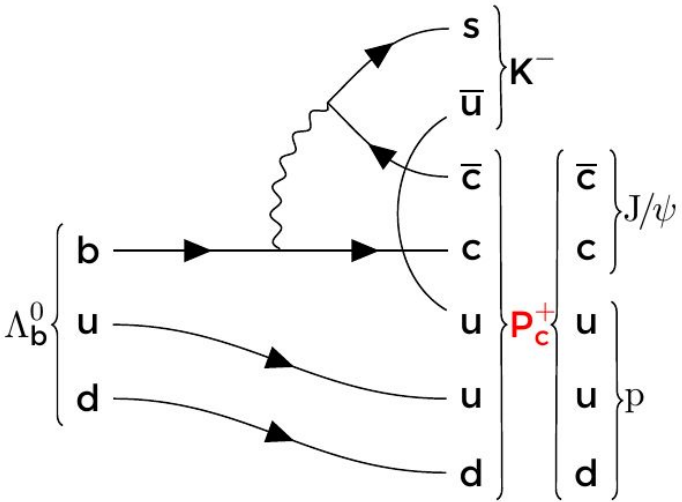
How can expertise in spectroscopy be better interfaced with flavour physics?

- Parametrisations of Dalitz-Plots
- Proposal by Brasilian Colleagues:
  - Use CPV observables as tool to learn about hadronic resonances
    - Charmless B-decays
- What about form factors?
  - What measurements are needed?
  - Where do we need to reach out to dedicated experiments?

Decay of the P_c to Open Charm

In preparation

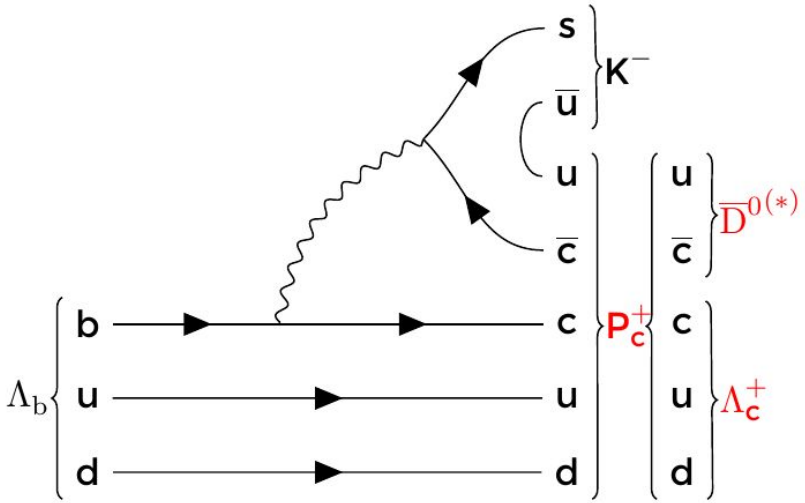
P_c discovery in $\Lambda_b \to J/\psi p K^-$



Molecular-Models:

$P_c^+ \to \Lambda_c^+ \overline{D}^{0(*)}$ favoured decay mode

[PRC85(2012)044002][↪ arXiv:1703.01045]



c and $\bar{c}$ in meson/baryon pair

Combined Analysis $\Lambda_b \to \Lambda_c^+ \overline{D}^0 K$ and $\Lambda_b \to \Lambda_c^+ \overline{D}^{0*} K$

- Predictions on relative widths ↪ arXiv:1703.01045

Mode	Widths (MeV)			
	$P_c(4380)$		$P_c(4450)$	
	$\bar{D}\Sigma_c^*(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{5}{2}^+)$
$\bar{D}^*\Lambda_c$	131.3	41.6	80.5	22.6
$J/\psi p$	3.8	8.4	8.3	2.0
$\bar{D}\Lambda_c$	1.2	17.0	41.4	18.8

- Possible spin-parity combinations for the $\Lambda_c^+ \overline{D}^{0(*)}$ system

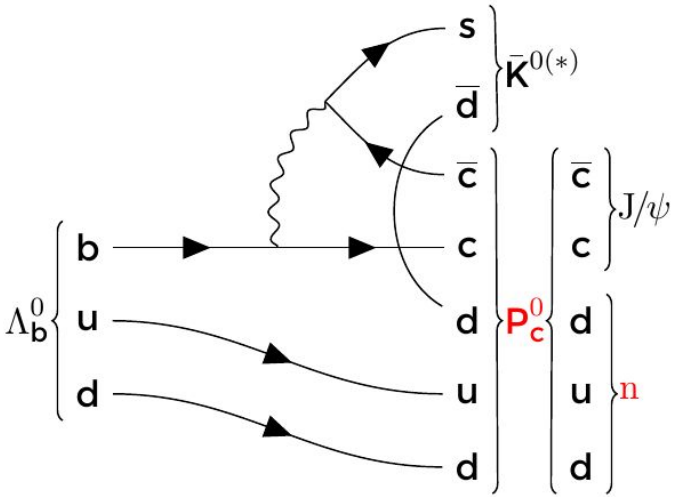
ℓ	$\Lambda_c^+ \overline{D}^0$	$\Lambda_c^+ \overline{D}^*$	pJ/ψ
S	$\frac{1}{2}^-$	$\frac{1}{2}^-, \frac{3}{2}^-$	$\frac{1}{2}^-, \frac{3}{2}^-$
P	$\frac{1}{2}^+, \frac{3}{2}^+$	$\frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+$	$\frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+$
D	$\frac{3}{2}^-, \frac{5}{2}^-$	$\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-$	$\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-$

favoured quantum numbers highlighted

- Complementary information on quantum numbers

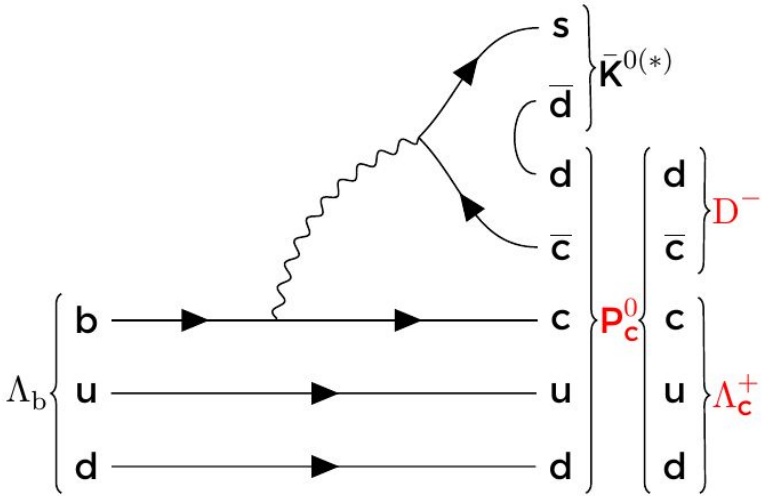
A neutral Pentaquark?

Are there isospin partners to the P_c^+? uudc$\bar{c}$ $\leftrightarrow$ uddc$\bar{c}$



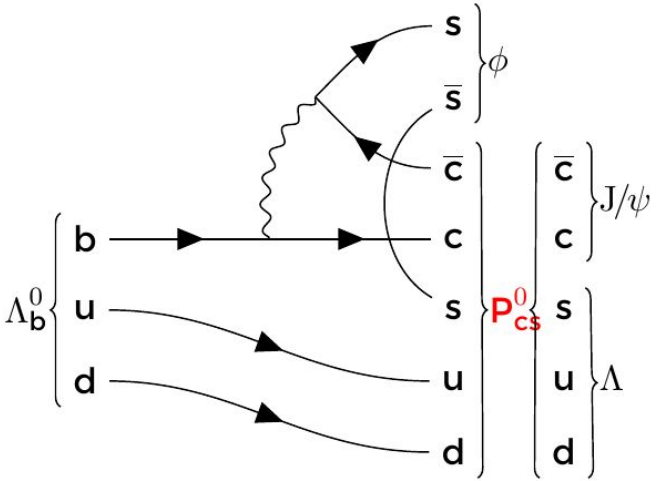
Neutron not detectable in LHCb

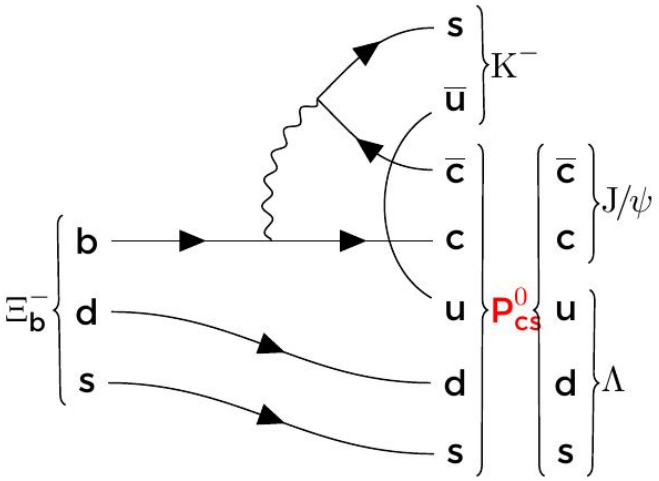
Decay into open charm hadrons accessible



Pentaquarks with Strangeness?

Both final states provide access to strange pentaquarks usdcc̄





- $J/\psi\phi$ system → cc̄ss̄ Tetraquarks
- LHCb Analyse $B \to J/\psi\phi K$:
  [PRL118(2017)022003]
  [PRD95(2017)012002]

- Less tracks reconstruct
- Lower Ξ_b production cross section
- Expect comparable statistics

Towards Many flavor Baryons

E.g: Phys. Rev. D 90, 094007 (2014)

Table XIII: Comparison of predictions for $M(\Xi_{bc})$.

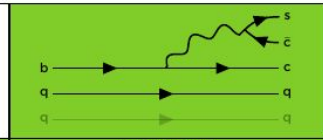
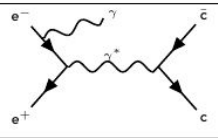
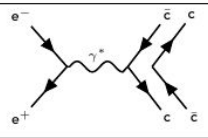
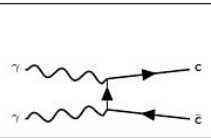
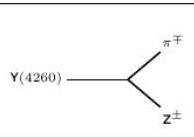
Reference	Value (MeV)	Method
Present work	6914 ± 13	
[25]	6916 ± 139	QCD-motivated quark model
[28]	6938	QCD-motivated quark model
[44]	6930	Potential models
[46]	6990 ± 90	Feynman-Hellmann + semi-empirical formul
[47]	7029	Mass sum rules
[48]	6950	Relativistic quasipotential quark model
[49]	6915	Three-body Faddeev equations.
[52]	6820 ± 50	Potential approach and QCD sum r
[53]	6960	Nonperturbative string
[54]	6933	Relativistic quark-diquark
[55]	6800	Bag model
[58]	6919	Variational
[59]	7011	Quark model
[60]	6789	Coupled channel formalism
[61]	6840 ± 10	Instantaneous approx. + Bethe-Salp
[62]	6750 ± 50	QCD sum rules

$$\sigma(pp \to \Xi_{bc} + X) \sim \sigma(pp \to \Xi_b + X) \cdot \frac{\sigma(pp \to \Xi_c + X)}{\sigma(pp \to \Xi + X)}$$

$$\sim \sigma(pp \to \Xi_c + X) \cdot \frac{\sigma(pp \to \Xi_b + X)}{\sigma(pp \to \Xi + X)}$$

Lifetimes

Baryon	This work	[28]	[52]	[71]	[72]
$\Xi_{cc}^{++} = ccu$	185	430±100	460±50	500	~ 200
$\Xi_{cc}^{+} = ccd$	53	120±100	160±50	150	~ 100
$\Xi_{bc}^{+} = bcu$	244	330±80	300±30	200	–
$\Xi_{bc}^{0} = bcd$	93	280±70	270±30	150	–
$\Xi_{bb}^{0} = bbu$	370	–	790±20	–	–
$\Xi_{bb}^{-} = bbd$	370	–	800±20	–	–

						$p\bar{p}$ incl.	pp incl.
$J/\psi\,\pi^+\pi^-$	X(3872)	Y(4260) Y(4008)				X(3872)	X(3872)
$\psi(2S)\,\pi^+\pi^-$		Y(4360) Y(4660)					
$\Lambda_c\overline{\Lambda}_c$		Y(4630)					
$\psi\gamma$	X(3872)						
$\chi_{c1}(1P)\,\gamma$	X(3832)						
$\chi_{c1}(1P)\,\omega$				Y(4220)			
$J/\psi\,\omega$	X(3872) Y(3940)			X(3915)			
$J/\psi\,\phi$	X(4140) X(4274) X(4500) X(4700)			X(4350)			
$J/\psi\,\pi$	Z(4430) Z(4200) Z(4240)				Z(3900)		
$\psi(2S)\,\pi$	Z(4430)						
$\chi_{c1}(1P)\,\pi$	Z(4051) Z(4248)						
$h_c(1P)\,\pi$					Z(4020)		
$D\overline{D}$				Z(3930)			
$D\overline{D}^*$	X(3872)		X(3940)		Z(3885)		
$D^*\overline{D}^*$			X(4160)		Z(4025)		
$J/\psi\,p$	$P_c(4380)$ $P_c(4430)$						

Exploiting different sources -- beyond the Upgrade

There are no spectroscopy studies with

- Bs
- Bc

as sources yet!

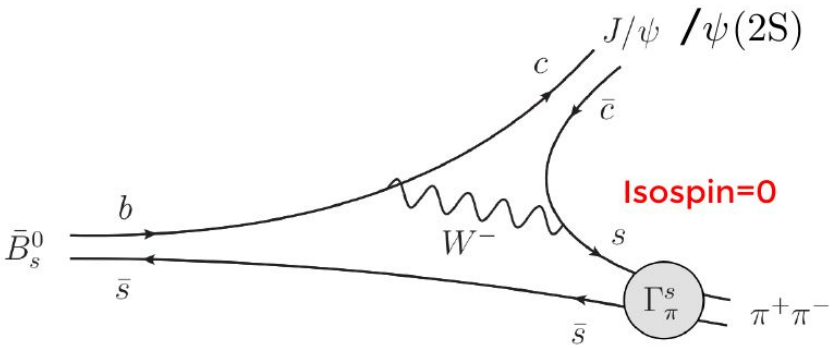
Study different production mechanisms

Heavy baryons are a unique sample, not available at Belle II!

It is not enough to find ground-state exotic states.
Excitation spectrum tells us about internal structure (exotic Regge trajectories)

Bs and Y(4260) as sources of exotic mesons?

Z(4430) in $B^0_{(s)} \to \psi(2S)\pi\pi$



(see also ↪ arXiv:1508:06841)

- B^0 decay Caibbo suppressed
- B^0_s on equal footing
- Compare exotic contributions in both channels!

Y(4260) in B-decays?

- Limit from BaBar: $B(B \to Y(4260)K \to J/\psi\pi\pi K) < 2.9 \times 10^{-5}$
  [PRD73(2006)011101]
- QCD sum rules:
  $3.0 \times 10^{-8} < 1.8 \times 10^{-6}$
  ↪ arXiv:1502.00119
- Could be produced in $B^0_s \to Y(4260)\phi$
- Isolate strangeness in well defined state (ϕ)
- 3-body final state instead of 4-body in B^+ decay