Recent LHCb Spectroscopy results.

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Representing the LHCb Collaboration

Outline:

- New results on light meson spectroscopy from B and B_s decays.
- New results on charm spectroscopy.

Workshop on Unquenched Hadron Spectroscopy:
Non-Perturbative Models and Methods of QCD vs. Experiment
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The LHCb experiment.

□ LHCb experiment is collecting very large samples of $c\bar{c}$ and $b\bar{b}$ events.

$$\sigma(b\bar{b}) \text{ at } 7 \text{ TeV} \approx 290 \mu\text{b}$$

$$\sigma(c\bar{c}) \approx 20 \times \sigma(b\bar{b})$$

□ Charmed events candidates are strongly suppressed by the trigger. Except for a few channels of interest.

□ Collected $\approx 3.2 \text{ fb}^{-1}$.

The LHCb experiment.

- Precise reconstruction of primary and secondary vertices (resolution = 45 fs for $B_s \rightarrow J/\psi\phi$).
- Excellent K/π separation (K identification efficiency = 95% with 5% of pion misidentification).
- All type of B hadrons produced: ($B^\pm$, B^0 , B_s^0 , b-baryons, $B_c^\pm$).
- Main issue for B and charm physics is the large vertex separation. Big boost, long-lived particles fly over long distances. Easy secondary vertex separation.

Light meson spectroscopy in B and B_s decays

- B and B_s decays can be used to obtain new information on the nature of light-quark resonances.
- Analysis of the resonant structures in $B^0 \rightarrow J/\psi \pi^+ \pi^-$ decays (arXiv:1404.5673).
- The decay can proceed either via a tree level process or via the penguin mechanisms.

- We expect an enhanced production of $I=0$ $u\bar{u} + d\bar{d}$ resonances.
- The puzzle of the scalar mesons has not been solved. Multiquark and glueball states may be present or mixed with $q\bar{q}$ states.
- Tests have been proposed to the scalar $f_0(500)$ and $f_0(980)$ mesons if they are formed of $q\bar{q}$ or tetraquarks (arXiv:1305.6554).

Dalitz plot analysis of $B^0 \rightarrow J/\psi \pi^+ \pi^-$

- The analysis makes use of total 3 fb^{-1} collected luminosity.
- The selection makes use of pre-selection cuts to enhance signal with respect to background.
- The final selection is obtained using a Bagged Decision Tree algorithm trained by Monte Carlo events for the signal and real data for the background.
- $J/\psi \pi^+ \pi^-$ effective mass: observe B^0 and B_s^0 signals.

- The mass fit to the B^0 peak gives $18\,841 \pm 204$ signal and $10\,207 \pm 178$ background candidates within ± 20 MeV of the B^0 mass peak.

Dalitz plot analysis of $B^0 \rightarrow J/\psi \pi^+ \pi^-$

□ B^0 Dalitz plot:

□ We observe horizontal uniform bands indicating the presence of resonant structures in the $\pi^+ \pi^-$ mass spectrum.

□ No resonances are observed in the $J/\psi \pi^\pm$ mass spectrum.

Dalitz plot analysis of $B^0 \rightarrow J/\psi \pi^+ \pi^-$

- Modified Dalitz plot analysis which includes also the J/ψ decay angle for different helicity states of intermediate resonances.
- Fit projection on the $\pi^+ \pi^-$ mass spectrum.

- Largest contribution is from $\rho(770)$ (63.1%),
- Smaller but significant contributions from $f_0(500)$ (22.2%), $f_2(1270)$ (7.5%), $\omega(782)$ (0.7%), $\rho(1450)$ (11.6%), and $\rho(1700)$ (5.1%).
- $f_0(980)$ contribution consistent with zero.

Mixing angle of $f_0(980)$

□ Assuming $f_0(500)$ and $f_0(980)$ belong to the same nonet:

$$|f_0(980)\rangle = \cos \varphi_m |s\bar{s}\rangle + \sin \varphi_m |n\bar{n}\rangle$$

$$|f_0(500)\rangle = -\sin \varphi_m |s\bar{s}\rangle + \cos \varphi_m |n\bar{n}\rangle$$

where $|n\bar{n}\rangle \equiv \frac{1}{\sqrt{2}} (|u\bar{u}\rangle + |d\bar{d}\rangle)$

□ From the Dalitz analysis we obtain:

$$\frac{\mathcal{B}(\bar{B}^0 \rightarrow J/\psi f_0(980), f_0(980) \rightarrow \pi^+\pi^-)}{\mathcal{B}(\bar{B}^0 \rightarrow J/\psi f_0(500), f_0(500) \rightarrow \pi^+\pi^-)} = (0.6^{+0.7+3.3}_{-0.4-2.6}) \times 10^{-2}$$

□ Using external information on the $f_0(980)$ branching fraction, we obtain.

$$\tan^2 \varphi_m = \frac{\mathcal{B}(\bar{B}^0 \rightarrow J/\psi f_0(980))}{\mathcal{B}(\bar{B}^0 \rightarrow J/\psi f_0(500))} \frac{\Phi(500)}{\Phi(980)} < 0.098 \quad \text{at 90\% C.L.}$$

where the Φ 's are phase space factors ($\Phi(500)/\Phi(980) = 1.25$).

□ This value is expected to be 1/2 for a pure tetraquark state. It deviates by 8σ from this hypothesis.

Dalitz plot analysis of $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$

- Leading diagram for $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ (arXiv:1402.6248).

- In this case we expect an enhanced production of $s\bar{s}$ resonances.
- The mass fit gives to the B_s^0 region gives 27396 ± 207 signal and 7075 ± 101 background candidates.

Dalitz plot analysis of $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$

□ Dalitz plot:

□ We observe resonant structures in the $\pi^+\pi^-$ mass spectrum.

Dalitz plot analysis of $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$

□ Fit projection on the $\pi^+ \pi^-$ mass spectrum.

Component	Solution I	Solution II
$f_0(980)$	$70.3 \pm 1.5^{+0.4}_{-5.1}$	$92.4 \pm 2.0^{+0.8}_{-16.0}$
$f_0(1500)$	$10.1 \pm 0.8^{+1.1}_{-0.3}$	$9.1 \pm 0.9 \pm 0.3$
$f_0(1790)$	$2.4 \pm 0.4^{+5.0}_{-0.2}$	$0.9 \pm 0.3^{+2.5}_{-0.1}$
$D - wave$	2.3	2.3
NR	-	$5.9 \pm 1.4^{+0.7}_{-4.6}$
Sum	85.2	110.6
χ^2/ndf	2005/1822	2008/1820

- Dominated by the presence of $f_0(980)$ and $f_0(1500)$.
- Other scalar or tensor contributions are small.
- Two solutions found with different $f_0(980)$ contributions.
- No evidence is found for $f_0(500)$.

Mixing angle of $f_0(980)$

- We obtain a upper limit for $f_0(500)$.

$$\frac{\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi f_0(500), f_0(500) \rightarrow \pi^+ \pi^-)}{\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi f_0(980), f_0(980) \rightarrow \pi^+ \pi^-)} < 3.4\% \text{ at } 90\% \text{ CL},$$

- Using external information on the $f_0(500)$ and $f_0(980)$ branching fractions, we obtain.

$$\tan^2 \varphi_m = \frac{\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi f_0(500)) \Phi(980)}{\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi f_0(980)) \Phi(500)} < 1.8\% \text{ at } 90\% \text{ CL}$$

- This translates into:

$$\varphi_m < 7.7^\circ \text{ at } 90\% \text{ C.L}$$

- which is the most stringent limit placed on this mixing angle.
- The value of $\tan^2 \varphi_m$ is consistent with the tetraquark model, which predicts zero within a few degrees.
- However due to the limited sensitivity on this channel it is also consistent with standard $q\bar{q}$ states.

Mixing angle of $f_1(1285)$

- Combined analysis of B^0 and B_s^0 decays to $J/\psi 4\pi$ (arXiv:1402.6248).
- $J/\psi 4\pi$ mass spectrum.

- There are 1193 ± 46 $\bar{B}_s^0$ and 839 ± 39 $\bar{B}^0$ decays.

Mixing angle of $f_1(1285)$

- The 4π mass spectrum for B^0 and B_s^0 decays.

- Signals of $f_1(1285)$ and structure around 1500 MeV in B_s^0 decays.
- Test of the helicity angle θ of the μ^+ from J/ψ decay with respect to the B momentum in the J/ψ rest frame.
- We expect helicity zero for scalar mesons, helicity ± 1 components for higher spin resonances.
- Observe important helicity ± 1 components in the $f_1(1285)$ region.
- The X(1500) resonance may be a mixture of $f_0(1500)$ and higher spin resonances.

Mixing angle of $f_1(1285)$

- The four-pion invariant mass distributions for $\bar{B}_s^0$ and $\bar{B}^0$ decays within ± 20 MeV of the $\bar{B}^0$ mass peaks.

- Obtain yields for $f_1(1285)$.
- We measure the branching fraction ratios

$$\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \pi^+ \pi^- \pi^+ \pi^-) / \mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \pi^+ \pi^-) = 0.371 \pm 0.015 \pm 0.022$$

$$\mathcal{B}(\bar{B}^0 \rightarrow J/\psi \pi^+ \pi^- \pi^+ \pi^-) / \mathcal{B}(\bar{B}^0 \rightarrow J/\psi \pi^+ \pi^-) = 0.361 \pm 0.017 \pm 0.021$$

Mixing angle of $f_1(1285)$

□ We obtain.

$$\frac{\mathcal{B}(\bar{B}^0 \rightarrow J/\psi f_1(1285))}{\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi f_1(1285))} = (11.6 \pm 3.1^{+0.7}_{-0.8})\%$$

□ The mixing angle ϕ is then given by

$$\tan^2 \phi = \frac{1}{2} \frac{\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi f_1(1285))}{\mathcal{B}(\bar{B}^0 \rightarrow J/\psi f_1(1285))} \frac{\tau_0}{\tau_s} \frac{|V_{cd}|^2}{|V_{cs}|^2} \frac{\Phi_0}{\Phi_s} = 0.1970 \pm 0.053^{+0.014}_{-0.012}$$

where τ_s is the $\bar{B}_s^0$ lifetime and τ_0 is the $\bar{B}^0$ lifetime.

□ We obtain:

$$\phi = \pm(24.0^{+3.1+0.6}_{-2.6-0.8})^\circ$$

□ The method allows the measurement of the mixing angle even if the mixing companion of this state is not detected.

□ The $f_1(1285)$ mixing angle has been estimated assuming that it is mixed with the $f_1(1420)$ state.

□ K.C. Yang (arXiv:1011.6113) finds $\phi = \pm(15.8^{+4.5}_{-4.6})^\circ$.

□ Another $J^{PC} = 1^{++}$ candidate is $f_1(1510)$ only observed in $(\pi/K)p$ interactions.

Charm meson spectroscopy

□ The quark model predicts many states with different quantum numbers in limited mass regions (Godfrey and Isgur, Phys.Rev.D32,189 (1985)).

□ In red are shown the established states.

□ The ground states (D, D^*), and two of the 1P states, $D_1(2420)$ and $D_2^*(2460)$, are experimentally well established since they have relatively narrow widths (~ 30 MeV).

Study of the $D\pi$ and $\pi^- D^{*+}$ systems in LHCb

□ We reconstruct the following final states (arXiv:1307.4556):

$$pp \rightarrow \mathbf{X} \ \pi^- \mathbf{D}^+ \rightarrow K^- \pi^+ \pi^+$$

$$pp \rightarrow \mathbf{X} \ \pi^+ \mathbf{D}^0 \rightarrow K^- \pi^+$$

$$pp \rightarrow \mathbf{X} \ \pi^- \mathbf{D}^{*+} \rightarrow \pi^+ D^0 \rightarrow K^- \pi^+$$

at 7 TeV, where $\mathbf{X}$ represents any collection of charged and neutral particles.

□ The analysis based on ($\approx 1 \text{ fb}^{-1}$) of data.

□ D^+ , D^0 , and D^{*+} signals.

The use of charge-conjugate decay modes is implied.

The $\cos\theta$ cut.

□ Combinatorial issues are strongly reduced by the use of the angle θ .

□ *For a $D^*\pi$ system, θ is the angle formed by the π in the $D^*\pi$ rest frame with the $D^*\pi$ direction in the Lab. frame.*

□ For an unpolarized two-body decay of a resonance, we expect the $\cos\theta$ distribution to be symmetric.

□ Combinatorial background concentrates at $\cos\theta < 0$. **Require $\cos\theta > 0$.**

□ Example from the $D^*\pi$ final state.

□ Signal to background for known resonances largely increases in the $\cos\theta > 0$ region.

$D^+\pi^-$ and $D^+\pi^+$ mass spectra.

- The $D^+\pi^-$ mass spectrum shows a cross-feed from the decay

$$D_1(2420)^0 \text{ or } D_2^*(2460)^0 \rightarrow \pi^- D^{*+} (\rightarrow D^+ \pi^0 / \gamma) \text{ (32.3\%)}$$

where the π^0/γ is not reconstructed.

- Strong $D_2^*(2460)^0$ signal and weak structures around 2600 and 2750 MeV.
- The wrong-sign $D^+\pi^+$ mass spectrum does not show any structure.

$D^0\pi^+$ and $D^0\pi^-$ mass spectra.

- The $D^0\pi^+$ mass spectrum shows a cross-feed from the decays:

$$D_1(2420)^+ \text{ or } D_2^*(2460)^+ \rightarrow \pi^+ D^{*0} (\rightarrow D^0\pi^0) (61.9\%)$$

$$(\rightarrow D^0\gamma) (38.1\%) .$$
- Strong $D_2^*(2460)^+$ signal and weak structures around 2600 and 2750 MeV.
- The wrong-sign $D^0\pi^-$ mass spectrum shows cross-feeds from:

$$D_1(2420)^0 \text{ or } D_2^*(2460)^0 \rightarrow \pi^- D^{*+} (\rightarrow D^0\pi^+) (67.7\%)$$

$D^{*+}\pi^-$ and the $D^{*+}\pi^+$ mass spectra.

- The $D^{*+}\pi^-$ mass spectrum is dominated by the presence of the $D_1(2420)^0$ and $D_2^*(2460)^0$ signals.
- At higher mass, complex broad structures in the mass region between 2500 and 2800 MeV.
- The wrong-sign $D^{*+}\pi^+$ mass spectrum does not show any structure.
- No cross-feeds in this final state.

Study of the $D^{*+}\pi^-$ angular distributions.

- Expected angular distributions for different spin assignments and MC simulations.

J^P	Helicity Distribution
0^+	decay not allowed
1^-	$\propto \sin^2 \theta_H$
2^+	$\propto \sin^2 \theta_H$
3^-	$\propto \sin^2 \theta_H$
0^-	$\propto \cos^2 \theta_H$
1^+	$\propto 1 + h \cos^2 \theta_H$
2^-	$\propto 1 + h \cos^2 \theta_H$

- States having $J^P = 0^+, 1^-, 2^+, 3^-, ..$ are defined as having “Natural Parity”.
- States having $J^P = 0^-, 1^+, 2^-, ...$ are defined as having “Unnatural Parity”.
- A resonance decaying to $D\pi$ has “Natural Parity”. Labelled with D^* .

Study of the $D^{*+}\pi^-$ angular distributions.

□ We divide the data into three samples:

$|\cos\theta_H| > 0.75$, **Enhanced Unnatural Parity Sample.**

$(0.55 \times 10^6$ events,

Natural Parity suppressed by a factor 11.6)

$|\cos\theta_H| < 0.5$, **Natural Parity Sample.**

$(0.98 \times 10^6$ events,

Natural Parity suppressed by a factor 1.5)

$|\cos\theta_H| > 0.5$, **Unnatural Parity Sample.**

$(1.06 \times 10^6$ events,

Natural Parity suppressed by a factor 3.2)

Fit to the *Enhanced Unnatural Parity* Sample.

- We expect Natural Parity consistent with zero.
- $D_2^*(2460)^0$ yield consistent with zero.
- Observe $D_1(2420)^0$.
- Observe three further structures:

$$D_J(2580)^0, D_J(2740)^0, D_J(3000)^0$$

Fit to the *Natural Parity* Sample.

- We expect Enhanced Natural Parity contributions.
- Observe $D_1(2420)^0$ and $D_2^*(2460)^0$.
- Fix the $D_J(2580)^0$, $D_J(2740)^0$, and $D_J(3000)^0$ parameters.
- Observe two further structures:

$$D_J^*(2650)^0, D_J^*(2760)^0$$

Fit to the *Unnatural Parity* Sample and *Total* Sample.

- Unnatural Parity Sample: fix all resonances parameters except for $D_1(2420)^0$.
- Total: all resonances parameters fixed.

Angular distributions (1).

□ Plot yields as functions of $\cos\theta_H$ for the different resonances.

□ $D_1(2420)^0$ has $J^P = 1^+$. Fitted with $1 + h\cos^2\theta_H$, $h = 3.30 \pm 0.48$. $\chi^2/\text{ndf} = 0.67/8$

□ $D_2^*(2460)^0$ has $J^P = 2^+$. Fitted with $\sin^2\theta_H$. $\chi^2/\text{ndf} = 8.5/9$

Angular distributions (2).

□ $D_J^*(2650)^0$ and $D_J^*(2760)^0$ are consistent with having Natural Parity.

□ Fitted with $\sin^2\theta_H$. $\chi^2/\text{ndf} = 6.8/9$ and $\chi^2/\text{ndf} = 5.8/9$ respectively.

(black: natural parity), (dashed red: unnatural parity), (dotted blue: $J^P = 0^-$)

Angular distributions (3).

□ $D_J(2580)^0$, $D_J(2740)^0$, and $D_J(3000)^0$ are consistent with having Unnatural Parity. Fitted with $1 + h\cos^2\theta_H$.

□ $\chi^2/\text{ndf} = 3.4/8$, $\chi^2/\text{ndf} = 6.6/8$ and $\chi^2/\text{ndf} = 10/8$, respectively.

(black: natural parity), (dashed red: unnatural parity),

(dotted blue: $J^P = 0^-$, $\chi^2/\text{ndf} = 23/9$)

Fit to the $D^+\pi^-$ and $D^0\pi^+$ mass spectra.

- Cross-feeds (in red) produce a distortion of the $D_2^*(2460)$ and $D_J^*(2650)$ lineshapes.

- For $D_J^*(2650)$ we rely on the results obtained from the $D^{*+}\pi^-$ mass analysis.
- We observe the $D_J^*(2760)$.
- The fits requires the presence of a broad structure around 3.0 GeV which we label $D_J^*(3000)$.

Resulting resonances parameters, yields and significances.

Resonance	Final state	Mass (MeV)			Width (MeV)			Yields $\times 10^3$	Sign.
$D_1(2420)^0$	$D^{*+}\pi^-$	2419.6 ± 0.1	± 0.7		35.2 ± 0.4	± 0.9		$210.2 \pm 1.9 \pm 0.7$	
$D_2^*(2460)^0$	$D^{*+}\pi^-$	2460.4 ± 0.4	± 1.2		43.2 ± 1.2	± 3.0		$81.9 \pm 1.2 \pm 0.9$	
$D_J^*(2650)^0$	$D^{*+}\pi^-$	2649.2 ± 3.5	± 3.5		140.2 ± 17.1	± 18.6		$50.7 \pm 2.2 \pm 2.3$	24.5
$D_J^*(2760)^0$	$D^{*+}\pi^-$	2761.1 ± 5.1	± 6.5		74.4 ± 3.4	± 37.0		$14.4 \pm 1.7 \pm 1.7$	10.2
$D_J(2580)^0$	$D^{*+}\pi^-$	2579.5 ± 3.4	± 5.5		177.5 ± 17.8	± 46.0		$60.3 \pm 3.1 \pm 3.4$	18.8
$D_J(2740)^0$	$D^{*+}\pi^-$	2737.0 ± 3.5	± 11.2		73.2 ± 13.4	± 25.0		$7.7 \pm 1.1 \pm 1.2$	7.2
$D_J(3000)^0$	$D^{*+}\pi^-$	2971.8 ± 8.7			188.1 ± 44.8			9.5 ± 1.1	9.0
$D_2^*(2460)^0$	$D^+\pi^-$	2460.4 ± 0.1	± 0.1		45.6 ± 0.4	± 1.1		$675.0 \pm 9.0 \pm 1.3$	
$D_J^*(2760)^0$	$D^+\pi^-$	2760.1 ± 1.1	± 3.7		74.4 ± 3.4	± 19.1		$55.8 \pm 1.3 \pm 10.0$	17.3
$D_J^*(3000)^0$	$D^+\pi^-$	3008.1 ± 4.0			110.5 ± 11.5			17.6 ± 1.1	21.2
$D_2^*(2460)^+$	$D^0\pi^+$	2463.1 ± 0.2	± 0.6		48.6 ± 1.3	± 1.9		$341.6 \pm 22.0 \pm 2.0$	
$D_J^*(2760)^+$	$D^0\pi^+$	2771.7 ± 1.7	± 3.8		66.7 ± 6.6	± 10.5		$20.1 \pm 2.2 \pm 1.0$	18.8
$D_J^*(3000)^+$	$D^0\pi^+$	3008.1 (fixed)			110.5 (fixed)			7.6 ± 1.2	6.6

□ Significances are evaluated as $\sqrt{\Delta\chi^2}$ where $\Delta\chi^2$ is the difference between the χ^2 values when a resonance is included or excluded from the fit.

□ Significances are all above 5σ .

□ We do not evaluate systematic uncertainties on the parameters of the $D_J^*(3000)/D_J(3000)$ structures because at the edge of the mass spectra.

Discussion.

- The $D_J^*(2650)^0$ resonance could be identified as a $J^P = 1^-$ state (2S $D_1^*(2618)$).
- The $D_J^*(2760)^0$ could be identified as a $J^P = 1^-$ state (1D $D_1^*(2796)$).
- The $D_J(2580)^0$ could be identified with the (2S $D_0(2558)$) state, although $J^P = 0^-$ does not fit well the data.
- The $D_J(2740)^0$ could be identified as the $J^P = 2^-$ (1D $D_2(2801)$) resonance.
- Broad structures are observed around 3.0 GeV in the $D^{*+}\pi^-$ and $D\pi$ mass spectra. They could be superpositions of several states.

Experimental status of the D_s mesons.

- Large discrepancy between theory predictions and experiment for $D_{s0}^*(2317)$ and $D_{s1}(2460)$.
- These two states have masses below the DK and D^*K respectively, therefore very narrow.

Study of excited D_s states in LHCb.

□ We reconstruct the following final states (1.0 fb^{-1} of data)_{(JHEP1210(2012)151)}:

$$pp \rightarrow X \quad \mathbf{K_S^0 D^+} \rightarrow K^- \pi^+ \pi^+ , \quad pp \rightarrow X \quad \mathbf{K^+ D^0} \rightarrow K^- \pi^+$$

□ Similar strategy as in the $D^{(*)}\pi$ analysis.

□ Select events with $\cos\theta > 0$.

□ D^+ and D^0 signals.

Study of Excited D_s states in LHCb.

□ Obtain 0.36×10^6 $D^+ K_S^0$ and 3.15×10^6 $D^0 K^+$ candidates.

□ First observation of $D_{s1}^*(2710)^+$ and $D_{sJ}^*(2860)^+$ in hadronic collisions.

$D_{s1}^*(2710)^+$ and $D_{sJ}^*(2860)^+$ parameters.

$$\begin{aligned} m(D_{s1}^*(2710)^+) &= 2709.2 \pm 1.9(\text{stat}) \pm 4.5(\text{syst}) \text{ MeV}/c^2, \\ \Gamma(D_{s1}^*(2710)^+) &= 115.8 \pm 7.3(\text{stat}) \pm 12.1(\text{syst}) \text{ MeV}/c^2, \\ m(D_{sJ}^*(2860)^+) &= 2866.1 \pm 1.0(\text{stat}) \pm 6.3(\text{syst}) \text{ MeV}/c^2, \\ \Gamma(D_{sJ}^*(2860)^+) &= 69.9 \pm 3.2(\text{stat}) \pm 6.6(\text{syst}) \text{ MeV}/c^2. \end{aligned}$$

- Resonances observed in BaBar and Belle have been confirmed. All results are in agreement.
- The statistical uncertainties for all parameters are improved by an overall factor of two with respect to the BaBar measurements in the same decay modes.
- An angular analysis of $D^* K$ samples is needed.

Discussion

□ Recent calculation of the $c\bar{s}$ spectrum from S. Godfrey and I.T. Jardine

(arXiv:1312.6181).

□ See also P. Colangelo et al., arXiv:1207.6940.

□ Expect several other states in this mass region.

□ It is possible that more than one state is contributing in both $D_{s1}^*(2710)$ and $D_{sJ}^*(2860)$ mass regions.

□ The possible existence of charm-strange hadronic molecules has been proposed (F. Guo et al. arXiv:1403.4032).

Dalitz plot analysis of $B_s^0 \rightarrow \bar{D}^0 K^- \pi^+$.

- Bagged Decision Tree method to obtain a good signal/background ratio.
- $\bar{D}^0 K^- \pi^+$ mass spectrum.

- 11302 ± 159 signal events. 12 954 total.
- Veto $D^0 \rightarrow K^- \pi^+$.
- $\bar{D}^0$ and B_s^0 mass constraints applied.

Dalitz plot analysis of $B_s^0 \rightarrow \bar{D}^0 K^- \pi^+$.

□ Dalitz plot.

□ Clear presence of resonant structures showing the expected spin structures.

□ Standard Dalitz plot analysis.

Dalitz plot analysis of $B_s \rightarrow \bar{D}^0 K^- \pi^+$.

□ The largest components are the $\bar{K}^*(892)^0$ (28.6 %), $D_{s2}^*(2573)^-$ (25.7 %), LASS (21.4 %) and $\bar{D}^0 K^-$ nonresonant (12.4 %) terms.

□ Fit projections.

□ A signal is present in the 2860 MeV $\bar{D}^0 K^-$ mass region which is described by a superposition of a spin-1 and spin-3 resonances.

Dalitz plot analysis of $B_s \rightarrow \bar{D}^0 K^- \pi^+$.

□ Different spin combinations have been tried:

Spin hypothesis	ΔNLL	$\sqrt{2\Delta\text{NLL}}$	Masses and widths			
1+3	0	—				
0	141.0	16.8	2862	57		
0+1	113.2	15.0	2446	250	2855	96
0+2	155.1	17.6	2870	61	2569	17
0+3	105.1	14.5	2415	188	2860	52
1	156.8	17.7	2866	92		
1+2	138.6	16.6	2851	99	3134	174
2	287.9	24.0	3243	81		
2	365.5	27.0	2569	17		
2+3	131.2	16.2	2878	12	2860	56
3	136.5	16.5	2860	57		

Dalitz plot analysis of $B_s \rightarrow \bar{D}^0 K^- \pi^+$.

- The fit fractions for the $D_{s1}^*(2860)^-$ and $D_{s3}^*(2860)^-$ components are $(5.0 \pm 1.2 \pm 0.7 \pm 3.3) \%$ and $(2.2 \pm 0.1 \pm 0.3 \pm 0.4) \%$.

- The masses and widths of the $D_{s1}^*(2860)^-$ and $D_{s3}^*(2860)^-$ states are determined to be:

$$m(D_{s1}^*(2860)^-) = 2859 \pm 12 \pm 6 \pm 23 \text{ MeV}/c^2, \Gamma(D_{s1}^*(2860)^-) = 159 \pm 23 \pm 27 \pm 72 \text{ MeV}/c^2$$

$$m(D_{s3}^*(2860)^-) = 2860.5 \pm 2.6 \pm 2.5 \pm 6.0 \text{ MeV}/c^2, \Gamma(D_{s3}^*(2860)^-) = 53 \pm 7 \pm 4 \pm 6 \text{ MeV}/c^2$$

Conclusions.

- There is a large activity in spectroscopy within LHCb experiment.
- Studies have been performed and analyses are in progress on light meson spectroscopy in B decays, charm spectroscopy in inclusive and B decays, charmonium spectroscopy, search for exotics, B^* , B_s^* and B_c^* spectroscopy, bottomonium spectroscopy, etc.
- With the restarting of the data-taking in 2015 larger data samples will be recorded.
- With the future LHCb upgrade we expect further large increase of the available dataset.