Excited charm meson spectroscopy from B decays at LHCb

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Outline

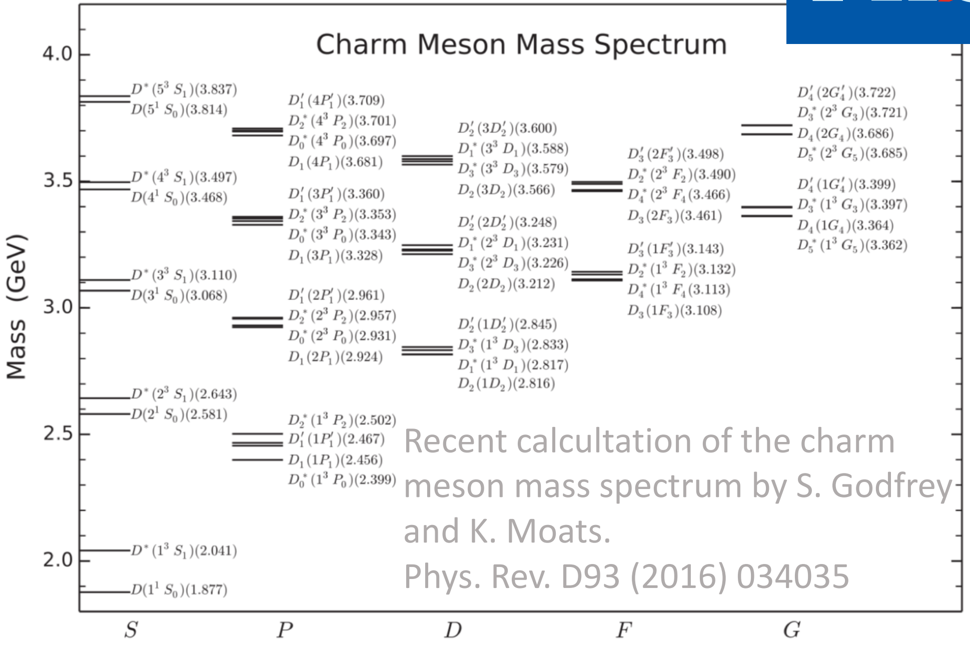
- Overview of the D_J spectroscopy.
- The experimental study of the D_J mass spectrum.
- Selected LHCb results.
  - Amplitude analysis of $B^- \to D^+\pi^-\pi^-$. Phys. Rev. D94 (2016) 072001
  - Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$. Phys. Rev. D 101 (2020) 032005

Charm meson spectroscopy

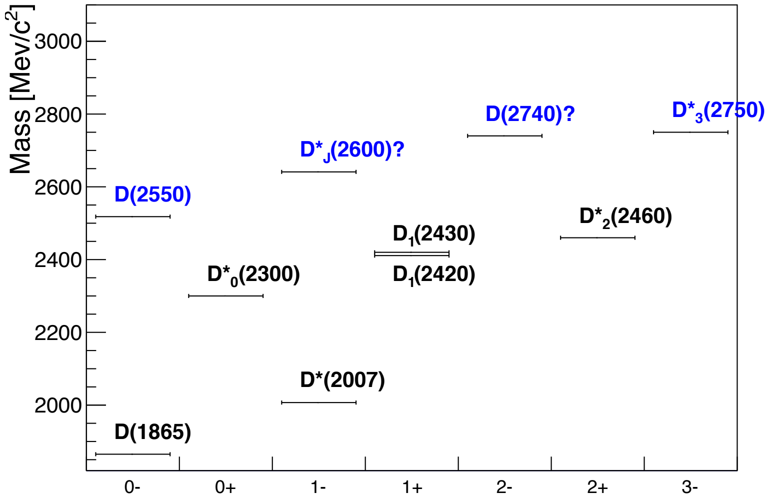
- Powerful test of quark-model predictions in the Standard Model.

Experimental status of the D_J spectroscopy.

- Two of the **1P orbital excitations** well established: **D_1(2420)** and **D^*_2(2460).** The other two members of the 1P multiplet being the broad **D^*_0(2300)** and **D_1(2430)**.
- Several new states (in blue) recently discovered in the $D\pi$ and $D^*\pi$ mass spectrum.



Recent calcultation of the charm meson mass spectrum by S. Godfrey and K. Moats.
Phys. Rev. D93 (2016) 034035



- *D_0(2550)*
- *D^*_J(2600)*
- *D(2740)*
- *D^*_3(2750)*

Observed in inclusive reactions by both BaBar (Phys.Rev.D82 (2010) 111101) and LHCb (JHEP (2013), 145)

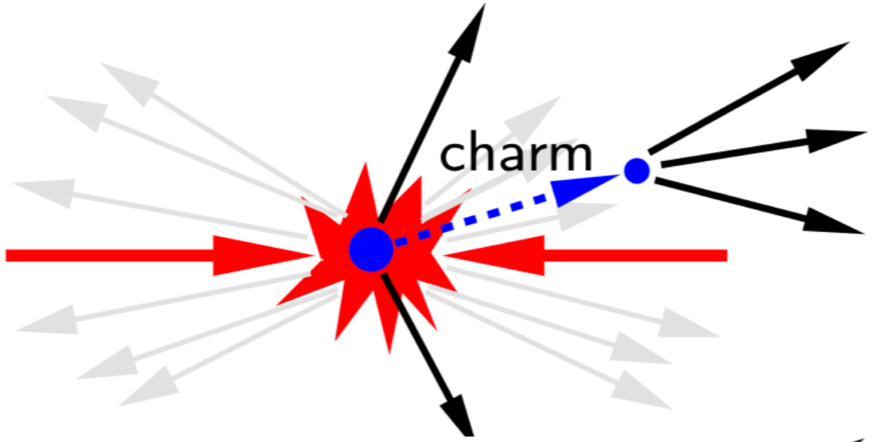
D^*_3(2750): $J^P = 3^-$ determined from the **amplitude analysis** of $B^- \rightarrow D^+\pi^-\pi^-$ (Phys. Rev. D94 (2016) 072001) by LHCb.
D_0(2550) angular distribution consistent with $J^P = 0^-$.
No definite assigment for the other resonances.

- States with $J^P = 0^+, 1^-, 2^+, 3^-$,... defined as having **Natural Parity.**
- States with $J^P = 0^-, 1^+, 2^-, 3^+$, ... defined as having **UnNatural Parity.**

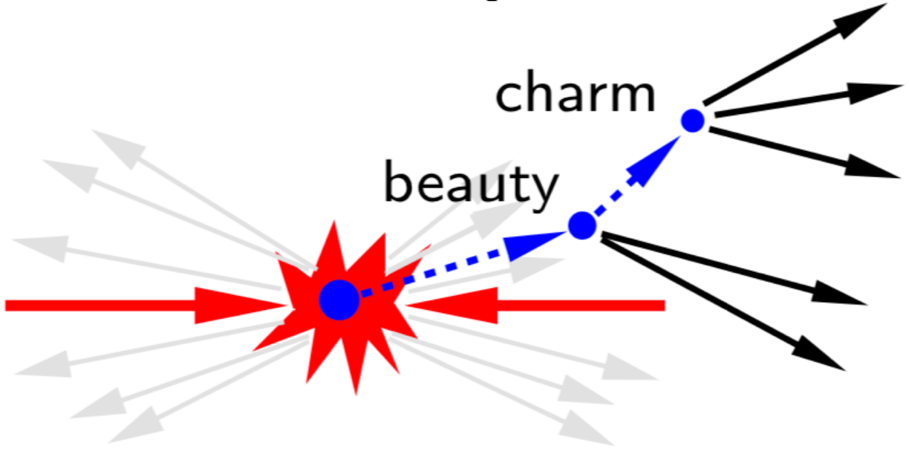
Experimental study of the D_J mass spectrum

Two different approaches for the searches of excited charm mesons:

1. Inclusive reactions, $pp \to D_J X$.
   - Large statistics.
   - Poor signal two background ratio.
   - No spin analysis for two body decays.
   - Only distinguishes between natural and unnatural spin-parity.



2. Amplitude analysis of multibody B decays.
   - Limited data samples.
   - Background usually low and well understood.
   - Full spin-parity analysis.
   - Presence of multiple interfering contributions.



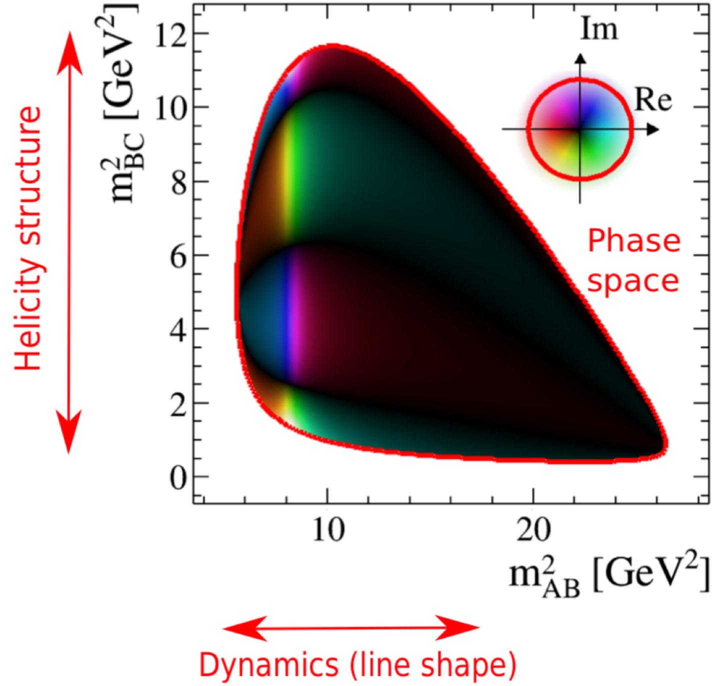
Amplitude Analysis

Powerful technique to study complex decay dynamics.

Fits of the amplitude as a function of phase space variables.

- Three body decays $D \rightarrow ABC$: two kinematic variables M^2_{AB}, M^2_{BC} (Dalitz plot).
- Add angular variables if initial/final states are not scalars.

A. Poluektov, Ecole de GIF (2018)



- **Model-dependent fits** typically isobar approach: sum of resonant/non-resonant components.
- More complicated models based on **unitarity**.
- **(Quasi) model-independent approaches**: some partial waves described as complex bins (splines).

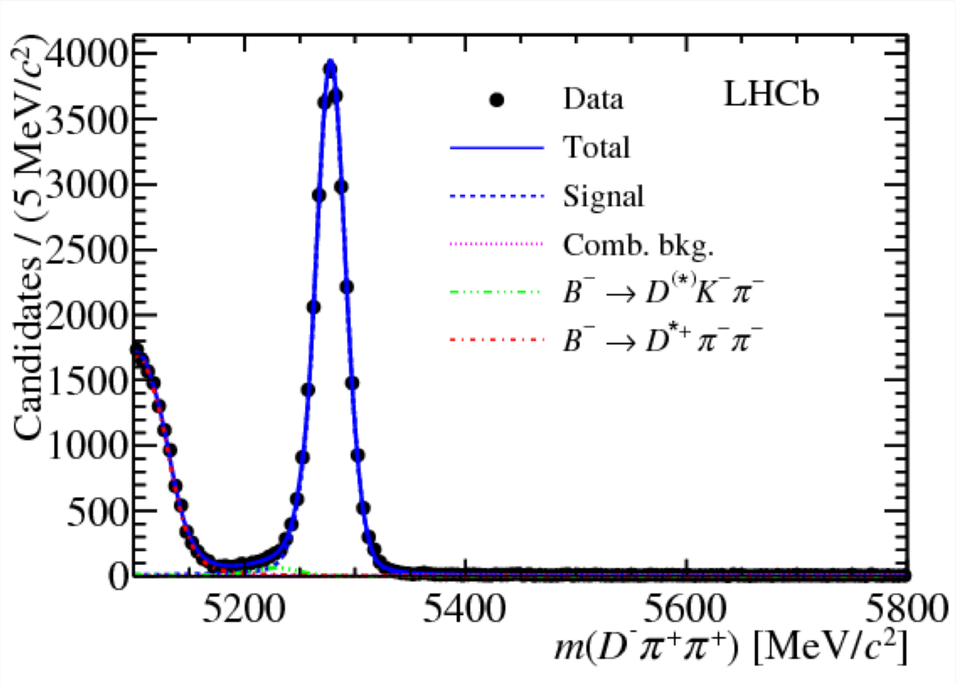
Line shape parameters and **spin** can be extracted.

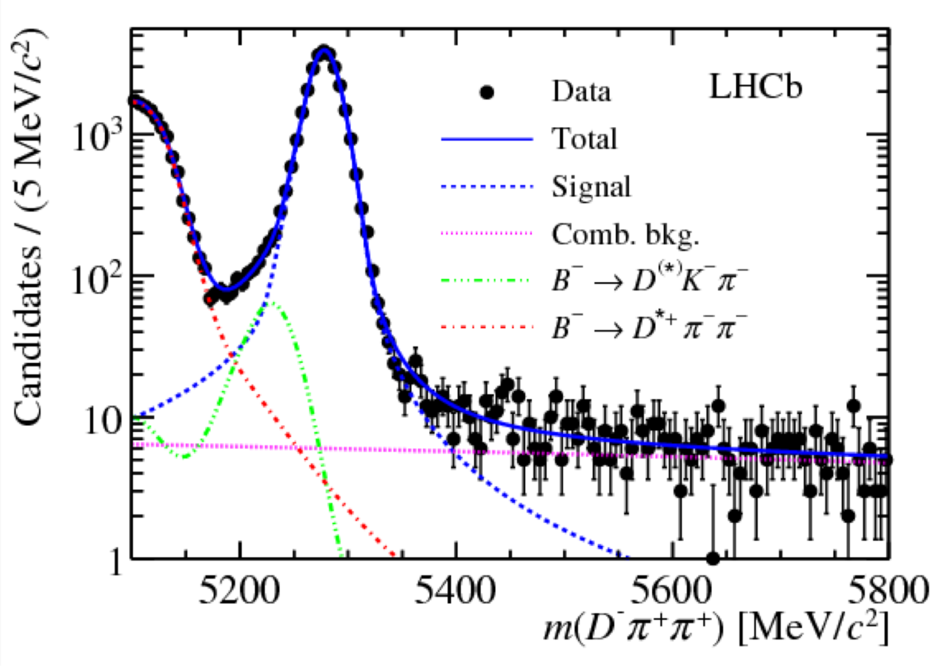
Selected results

Amplitude analysis of $B^- \to D^+\pi^-\pi^-$

[Phys. Rev. D94 (2016) 072001]

- Study excited states in the $D^+\pi^-$ channel.
- Access to natural spin-parity states.
- **Integrated luminosity: 3 fb^{-1},** Run 1 (7,8 TeV).
- Use of neural network to separate signal from different categories of background (29k events).





Amplitude analysis of $B^- \to D^+\pi^-\pi^-$

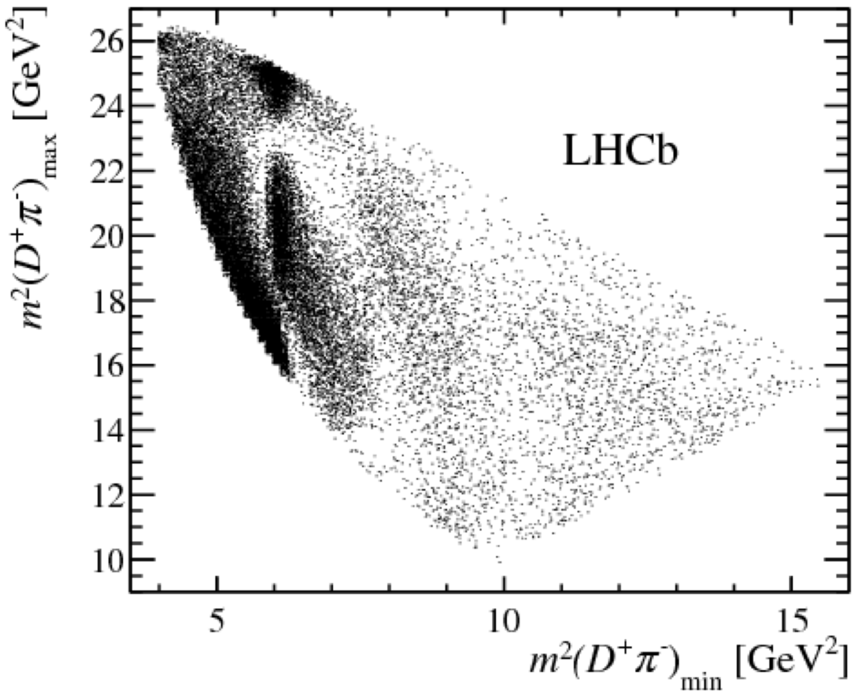
Phys. Rev. D94 (2016) 072001

The dalitz plot

- Two indistinguishable pions; $m^2(D^+\pi^-)$ ordered by value: $m^2_{min}(D^+\pi^-)$, $m^2_{max}(D^+\pi^-)$.

Nominal model

- Four resonances.
- Two virtual resonances.
- Quasi-model-independent (QMI) description of the S-wave.



Resonance	Spin	Model	Parameters
$D_2^*(2460)^0$	2	RBW	Determined from data (see Table IV)
$D_1^*(2680)^0$	1	RBW	
$D_3^*(2760)^0$	3	RBW	
$D_2^*(3000)^0$	2	RBW	
$D_v^*(2007)^0$	1	RBW	$m = 2006.98 \pm 0.15$ MeV, $\Gamma = 2.1$ MeV
B_v^{*0}	1	RBW	$m = 5325.2 \pm 0.4$ MeV, $\Gamma = 0.0$ MeV
Total S wave	0	MIPW	

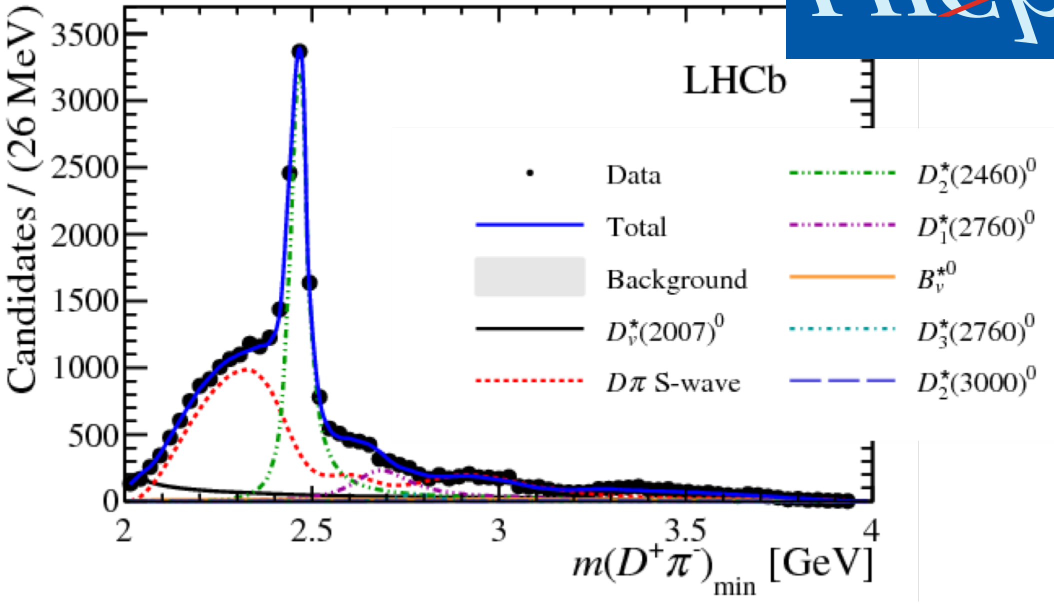
RBW = Relativistic Breit-Wigner.
MIPW = Model independent partial wave (spline)

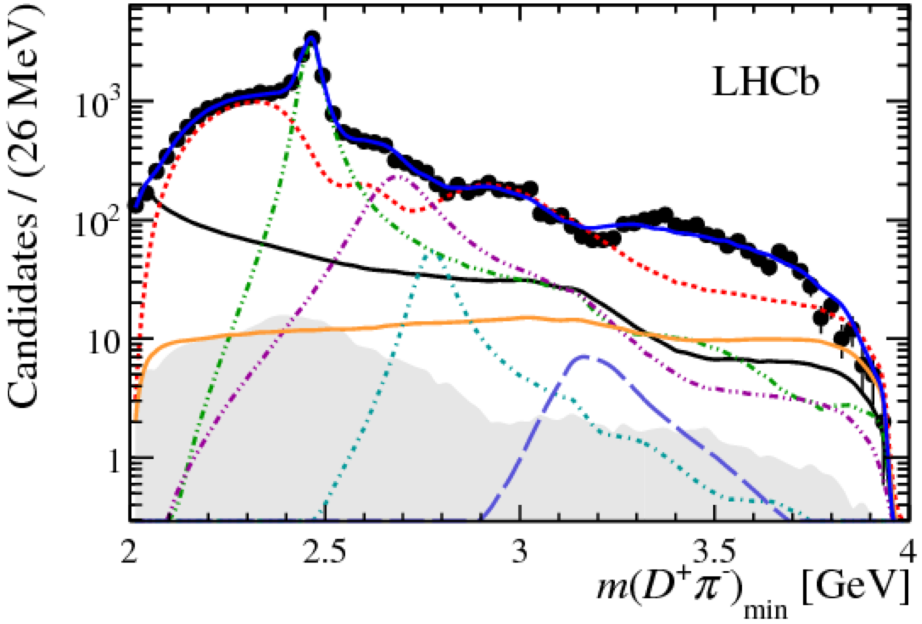
Amplitude analysis of $B^- \to D^+\pi^-\pi^-$

Phys. Rev. D94 (2016) 072001

Observations of the $D_3^*(2760)$ and $D_2^*(3000)$.

$$m(D_2^*(2460)^0) = 2463.7 \pm 0.4 \pm 0.4 \pm 0.6 \text{ MeV},$$
$$\Gamma(D_2^*(2460)^0) = 47.0 \pm 0.8 \pm 0.9 \pm 0.3 \text{ MeV},$$
$$m(D_1^*(2680)^0) = 2681.1 \pm 5.6 \pm 4.9 \pm 13.1 \text{ MeV},$$
$$\Gamma(D_1^*(2680)^0) = 186.7 \pm 8.5 \pm 8.6 \pm 8.2 \text{ MeV},$$
$$m(D_3^*(2760)^0) = 2775.5 \pm 4.5 \pm 4.5 \pm 4.7 \text{ MeV},$$
$$\Gamma(D_3^*(2760)^0) = 95.3 \pm 9.6 \pm 7.9 \pm 33.1 \text{ MeV},$$
$$m(D_2^*(3000)^0) = 3214 \pm 29 \pm 33 \pm 36 \text{ MeV},$$
$$\Gamma(D_2^*(3000)^0) = 186 \pm 38 \pm 34 \pm 63 \text{ MeV},$$



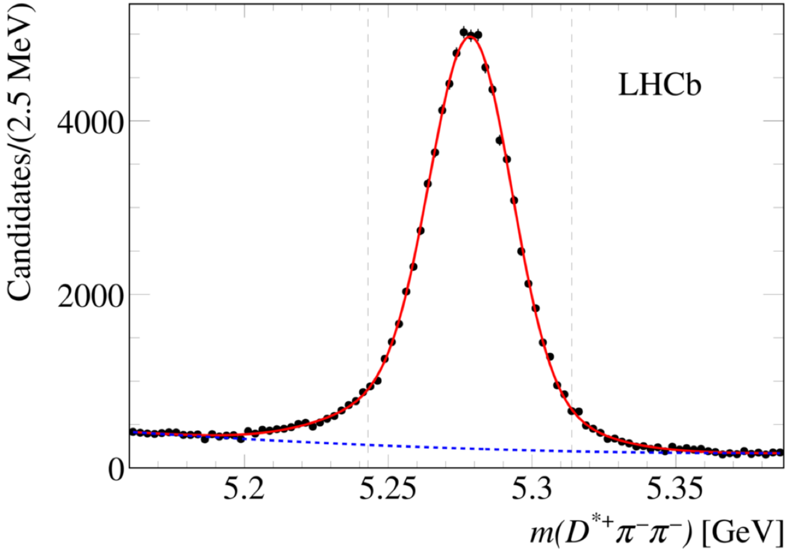


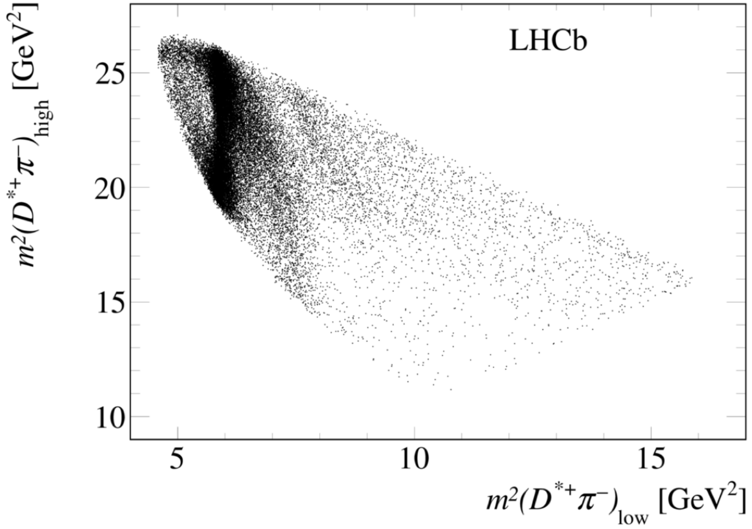
- Uncertainties are statistical, exp. systematic and model syst.
- Complete results of the amplitude fit in the back-ups.

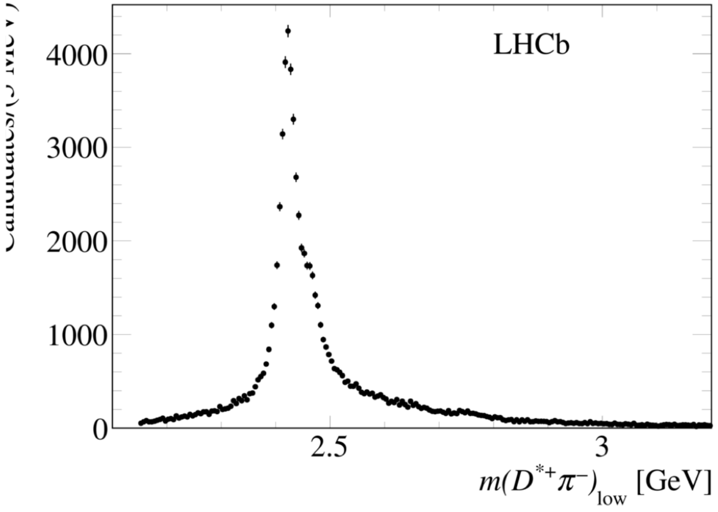
Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$

Phys. Rev. D 101 (2020) 032005

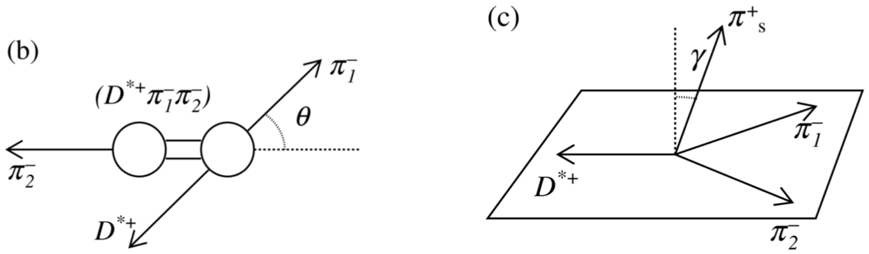
- Resonance production in the $D^{*+}\pi^-$ system.
- Both natural and unnatural spin-parity states.
- **4.7 fb^{-1}** : Run 1 (7, 8 TeV) and 2016 (13 TeV).
- 80k events, 90 % purity.







- 4D amplitude analysis:
  $m^2(D^*\pi)_{low}$, $m^2(D^*\pi)_{high}$;
  D^* angles: θ, γ



Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$

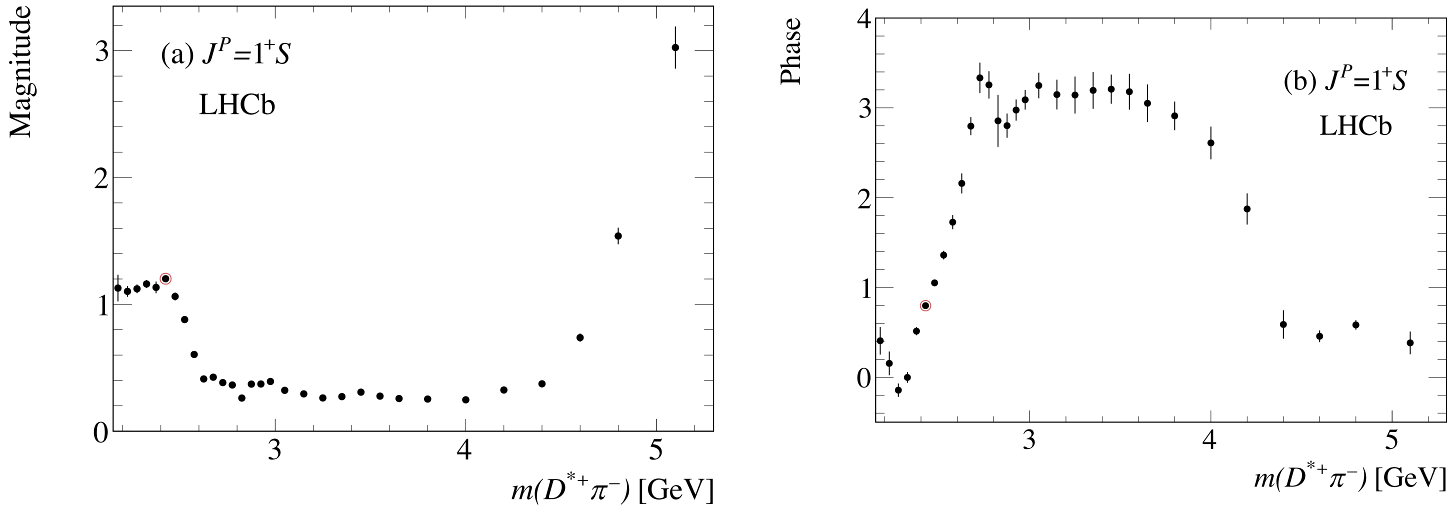
Phys. Rev. D 101 (2020) 032005

Different models to fit the data:

- Breit-Wigner only model.
- Quasi-Model-Independent (QMI) approach to describe the 1^+S and 0^- amplitudes.
- **Mixing** between the $J^P = 1^+$ **amplitudes.**

QMI amplitude for the broad $J^P = 1^+$.

- $D^{*+}\pi^-$ mass spectrum divided into 31 non-uniform bins.
- Breit-Wigner term replaced with 31 complex parameters (magnitude and phase) free to float.
- All other amplitudes described by relativistic BW.



Fitted magnitudes and phases of the 1⁺S amplitude.

Resonance	J^P
$D_1(2420)$	1^+
$D_1(2430)$	1^+
$D_2^*(2460)$	2^+
$D_0(2550)$	0^-
$D_1^*(2600)$	1^-
$D_2(2740)$	2^-
$D_3^*(2750)$	3^-

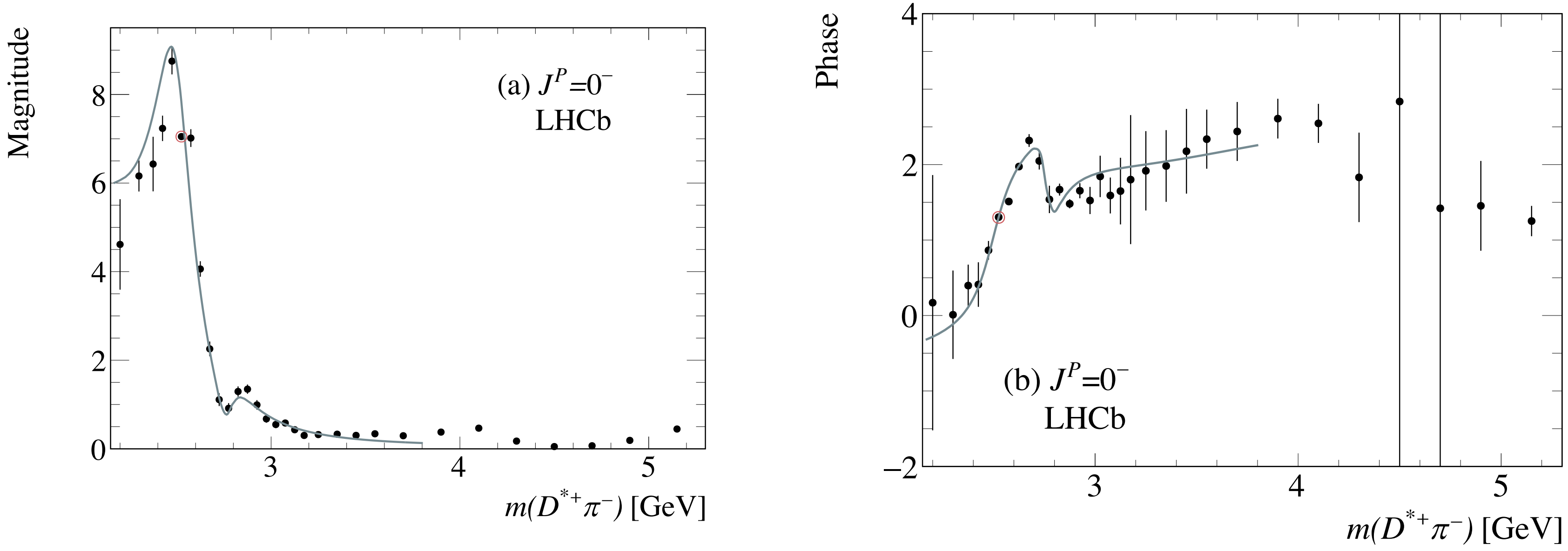
Amplitudes included.

Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$

[Phys. Rev. D (2020) 101, 032005]

QMI amplitude for the $J^P = 0^-$.

- **QMI $J^P = 1^+$**S fixed.
- Rest of the amplitudes described by relativistic Breit-Wigner.



- Process continues by fixing **the $J^P = 0^-$** QMI amplitude and leaving free the rest of the BW parameters .

Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$

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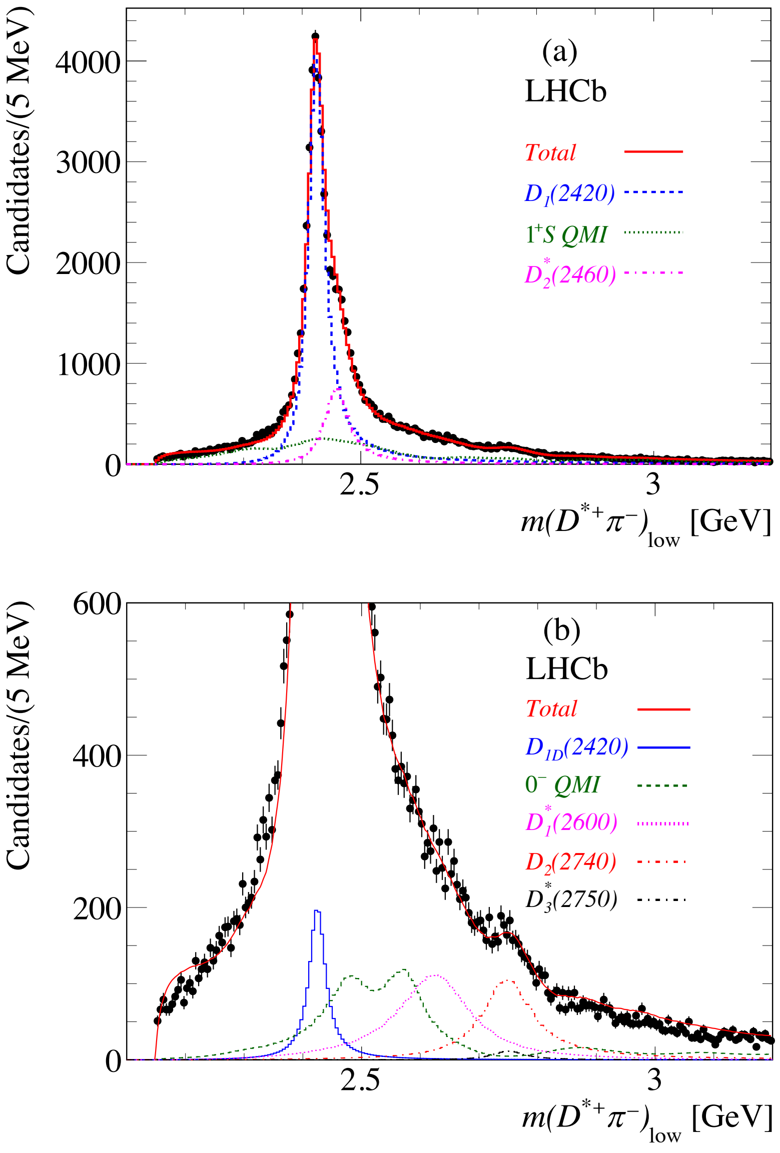


Results from the nominal model

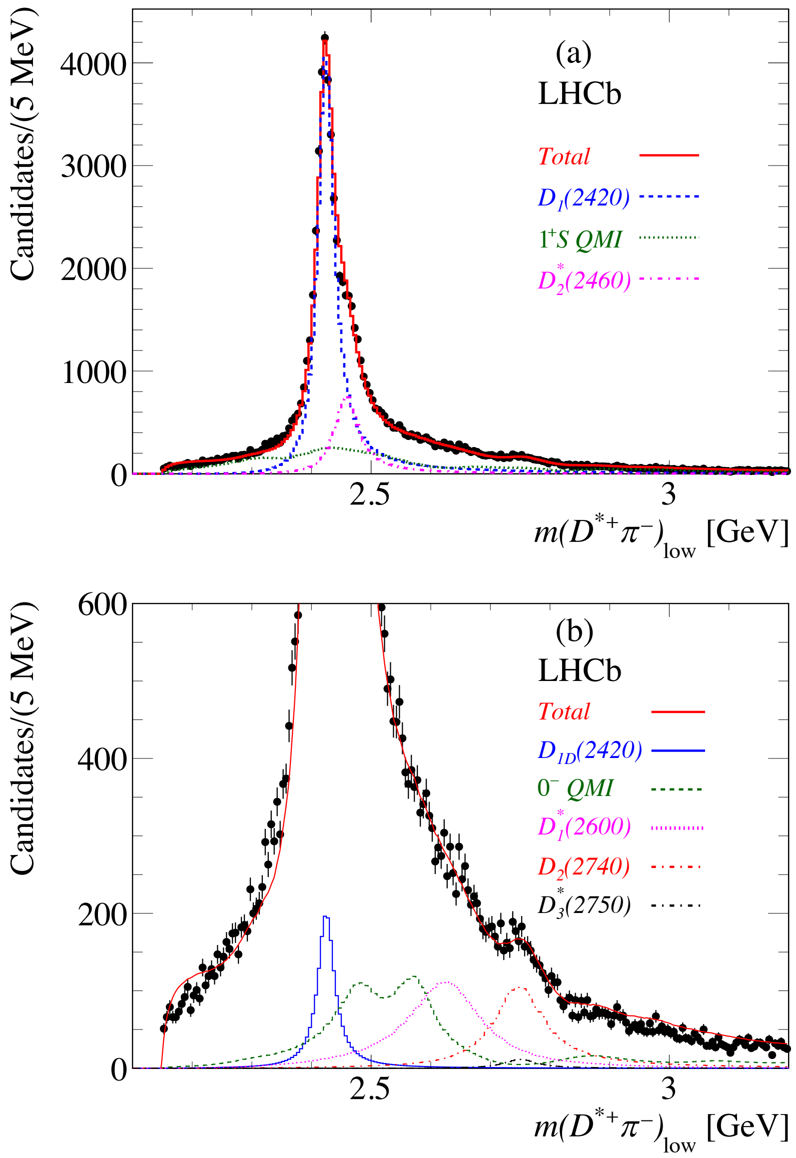
- QMI for the $J^P = 0^-$ and 1^+ S-wave.
- Resonance parameters and quantum numbers are determined.
- Breit-Wigner model to extract the *$D_0(2550)$* and *$D_1(2430)$* mass parameters.
- Complete results of the amplitude fit in the back-ups.

Resonance	J^P	Mass [MeV]	Width [MeV]	Significance (σ)
$D_1(2420)$	1^+	$2424.8 \pm 0.1 \pm 0.7$	$33.6 \pm 0.3 \pm 2.7$	
$D_1(2430)$	1^+	$2411 \pm 3 \pm 9$	$309 \pm 9 \pm 28$	
$D_2^*(2460)$	2^+	2460.56 ± 0.35	47.5 ± 1.1	
$D_0(2550)$	0^-	$2518 \pm 2 \pm 7$	$199 \pm 5 \pm 17$	53
$D_1^*(2600)$	1^-	$2641.9 \pm 1.8 \pm 4.5$	$149 \pm 4 \pm 20$	60
$D_2(2740)$	2^-	$2751 \pm 3 \pm 7$	$102 \pm 6 \pm 26$	16
$D_3^*(2750)$	3^-	$2753 \pm 4 \pm 6$	$66 \pm 10 \pm 14$	8.7
D_1	1^+	$2423.7 \pm 0.1 \pm 0.8$	$31.5 \pm 0.1 \pm 2.1$	
D_1'	1^+	$2452 \pm 4 \pm 15$	$444 \pm 11 \pm 36$	

Uncertainties are statistical and exp. systematic.

Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$

Phys. Rev. D 101 (2020) 032005



Results from the mixing model

- Mixing of 1^+ states.

$$A^{D'_1} = A^{1S}\cos\omega - A^{1D}\sin\omega e^{-i\psi}$$
$$A^{D_1} = A^{1S}\cos\omega - A^{1D}\sin\omega e^{-i\psi}$$

$$\omega = -0.063 \pm 0.019 \pm 0.004$$
$$\psi = -0.29 \pm 0.09 \pm 0.07$$

Resonance	J^P	Mass [MeV]	Width [MeV]	Significance (σ)
$D_1(2420)$	1^+	$2424.8 \pm 0.1 \pm 0.7$	$33.6 \pm 0.3 \pm 2.7$	
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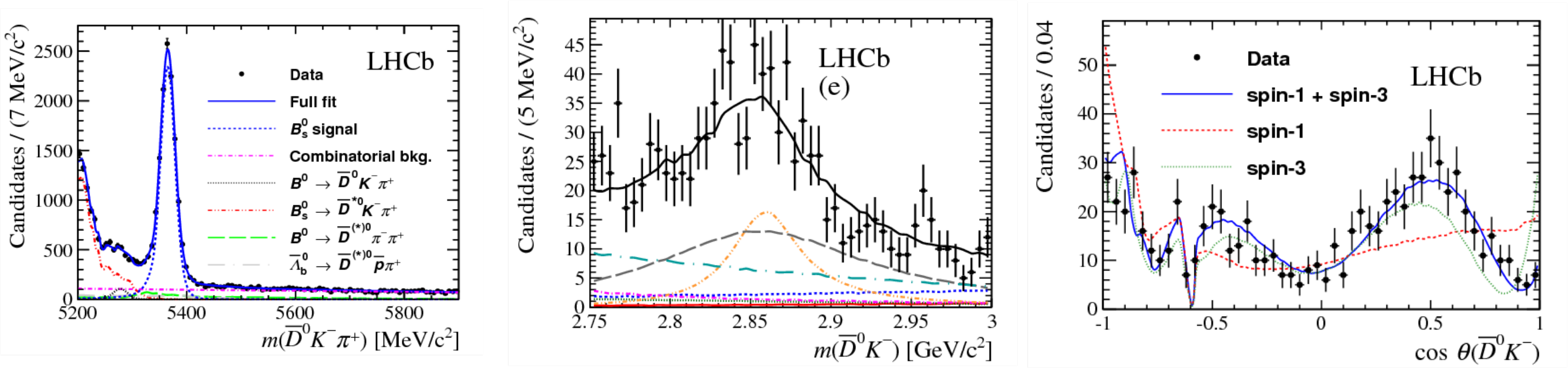
$D_3^*(2750)$	3^-	$2753 \pm 4 \pm 6$	$66 \pm 10 \pm 14$	8.7
D_1	1^+	$2423.7 \pm 0.1 \pm 0.8$	$31.5 \pm 0.1 \pm 2.1$	
D'_1	1^+	$2452 \pm 4 \pm 15$	$444 \pm 11 \pm 36$	

Charm-strange meson spectroscopy

Reminder of D_{sJ} spectroscopy from LHCb in 2014.

Phys. Rev. Lett. 113 (2014) 162001
Phys. Rev. D90 (2014) 072003

- Amplitude analysis of $B_s^0 \to \overline{D}^0 K^- \pi^+$ **decays**, 3 fb^{-1} Run 1.
- $D_{sJ}^*(2860)^-$ state resolved as an **admixture of spin-1 and spin-3 components**.

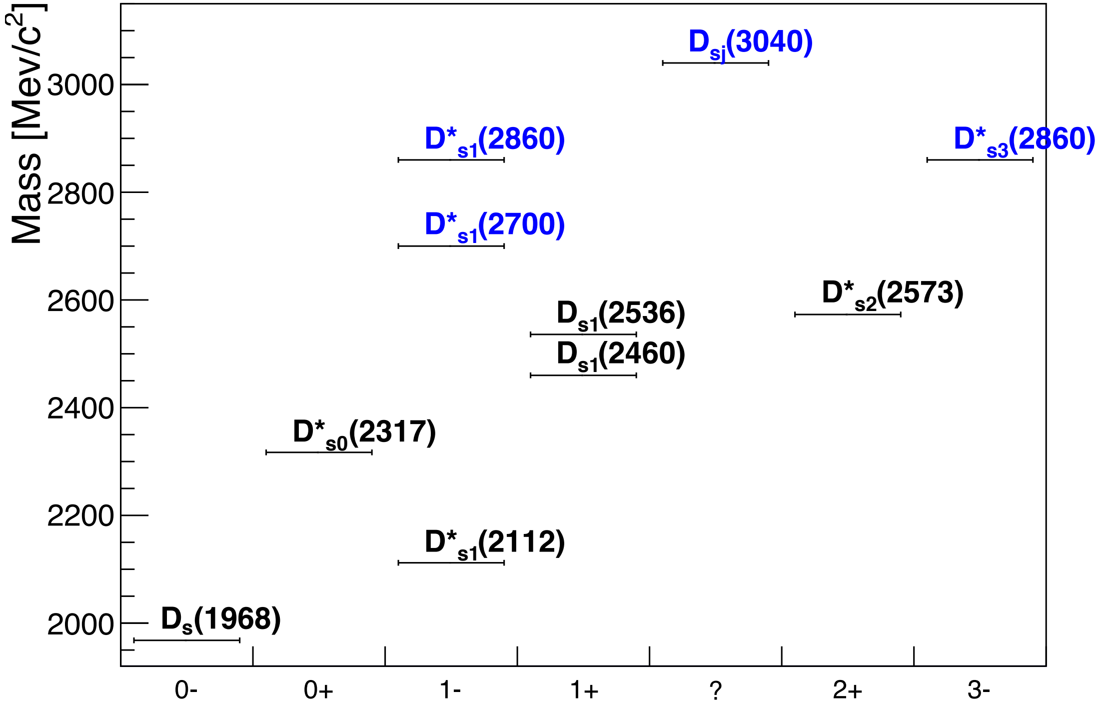


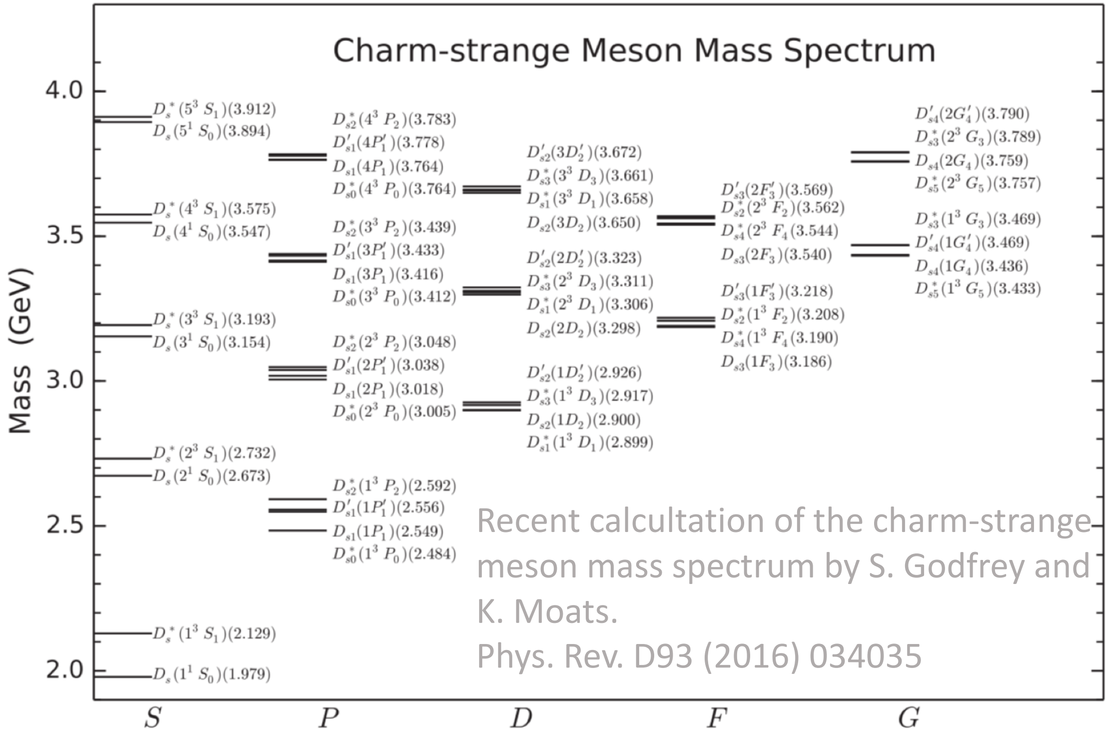
$m(D_{s1}^*(2860)^-) = 2859 \pm 12 \pm 6 \pm 23$ MeV/c^2 $\quad \Gamma(D_{s1}^*(2860)^-) = 159 \pm 23 \pm 27 \pm 72$ MeV/c^2

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

Uncertainties are statistical, experimental systematics and model systematics

Charm-strange meson spectroscopy





- **New discovered states (in blue) in the *DK* and *D*K* mass spectrum.**
- **Work in progress on the D_s meson spectroscopy from amplitude analysis of *B* and B_s decays at LHCb.**

Summary

- The resonance parameters and quantum numbers for several recently discovered D_J states have been determined from
  - Amplitude analysis of $\boldsymbol{B^- \to D^+ \pi^- \pi^-}$.
  - Amplitude analysis of $\boldsymbol{B^- \to D^{*+} \pi^- \pi^-}$.

- Mixing between $D_1(2420)$ and $D_1(2430)$ studied.
  - Mixing parameters have been measured.

- More ongoing analysis on charm and charm-strange spectroscopy from B decays at LHCb.

BACKUP SLIDES

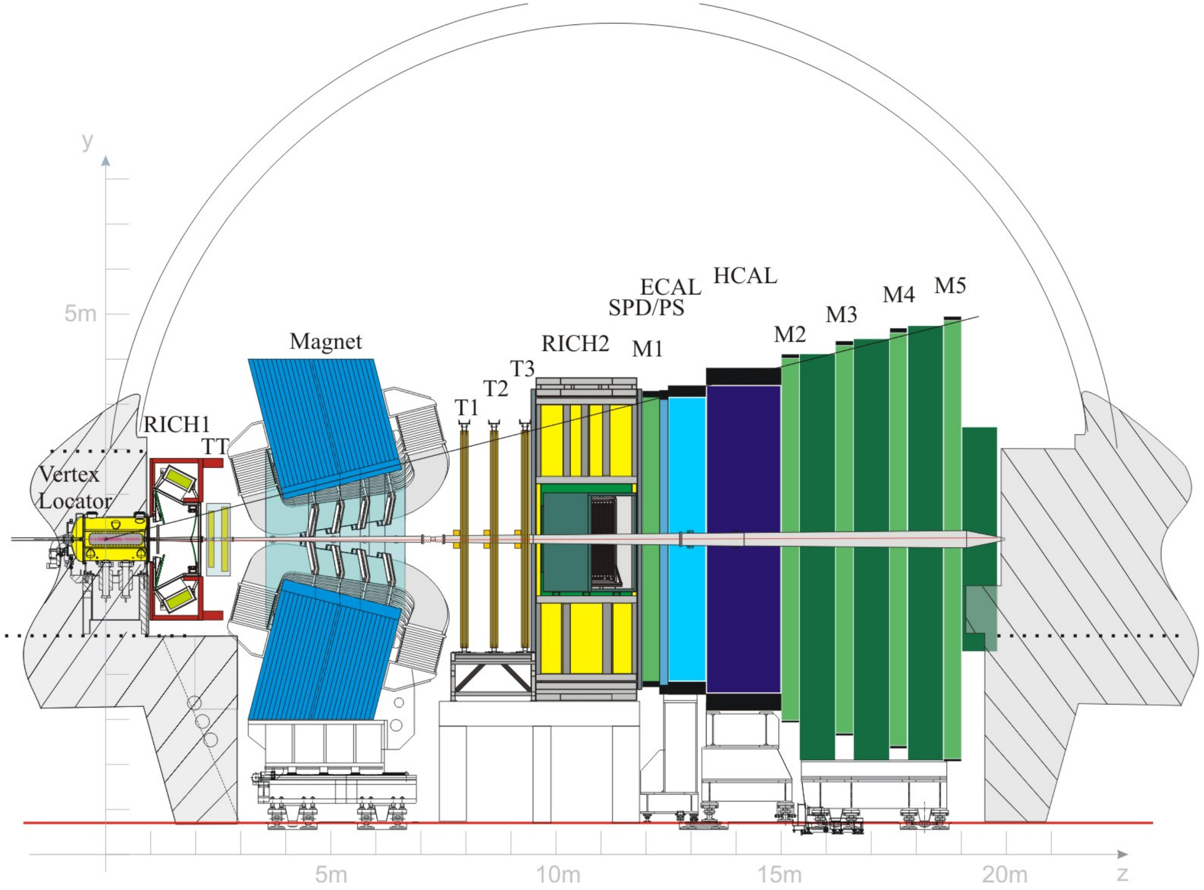
The LHCb detector

- Single arm forward spectrometer ($2 < \eta < 5$).
- Optimized for studies of **beauty and charm** decays at LHCb.

- High precision tracking.
  - Silicon strip vertex detector.
  - 4 Tm dipole magnet
  - Silicon strip + straw drift tubes downstream the magnet.

- Particle Identification
  - RICH, electromagnetic and hadronic calorimeters, muon stations.

- Efficient trigger, including **fully hadronic modes**.



Amplitude analysis of $B^- \to D^+\pi^-\pi^-$

Phys. Rev. D94 (2016) 072001

TABLE V. Complex coefficients and fit fractions determined from the Dalitz plot fit. Uncertainties are statistical only.

	Isobar model coefficients				
Contribution	Fit fraction (%)	Real part	Imaginary part	Magnitude	Phase (rad)
$D_2^*(2460)^0$	35.7 ± 0.6	1.00	0.00	1.00	0.00
$D_1^*(2680)^0$	8.3 ± 0.6	-0.38 ± 0.02	0.30 ± 0.02	0.48 ± 0.02	2.47 ± 0.09
$D_3^*(2760)^0$	1.0 ± 0.1	0.17 ± 0.01	0.00 ± 0.01	0.17 ± 0.01	0.01 ± 0.20
$D_2^*(3000)^0$	0.23 ± 0.07	0.05 ± 0.02	-0.06 ± 0.02	0.08 ± 0.01	-0.84 ± 0.28
$D_v^*(2007)^0$	10.8 ± 0.7	0.51 ± 0.03	-0.20 ± 0.05	0.55 ± 0.02	-0.38 ± 0.19
B_v^{*0}	2.7 ± 1.0	0.27 ± 0.03	0.04 ± 0.04	0.27 ± 0.05	0.14 ± 0.38
Total S wave	57.0 ± 0.8	1.21 ± 0.02	-0.35 ± 0.04	1.26 ± 0.01	-0.28 ± 0.05
Total fit fraction	115.7				

Amplitude analysis of $B^- \to D^+\pi^-\pi^-$

Phys. Rev. D94 (2016) 072001

TABLE XI. Results for the product branching fractions $\mathcal{B}(B^- \to R\pi^-) \times \mathcal{B}(R \to D^+\pi^-)$. The four quoted errors are statistical, experimental systematic, model and inclusive branching fraction uncertainties.

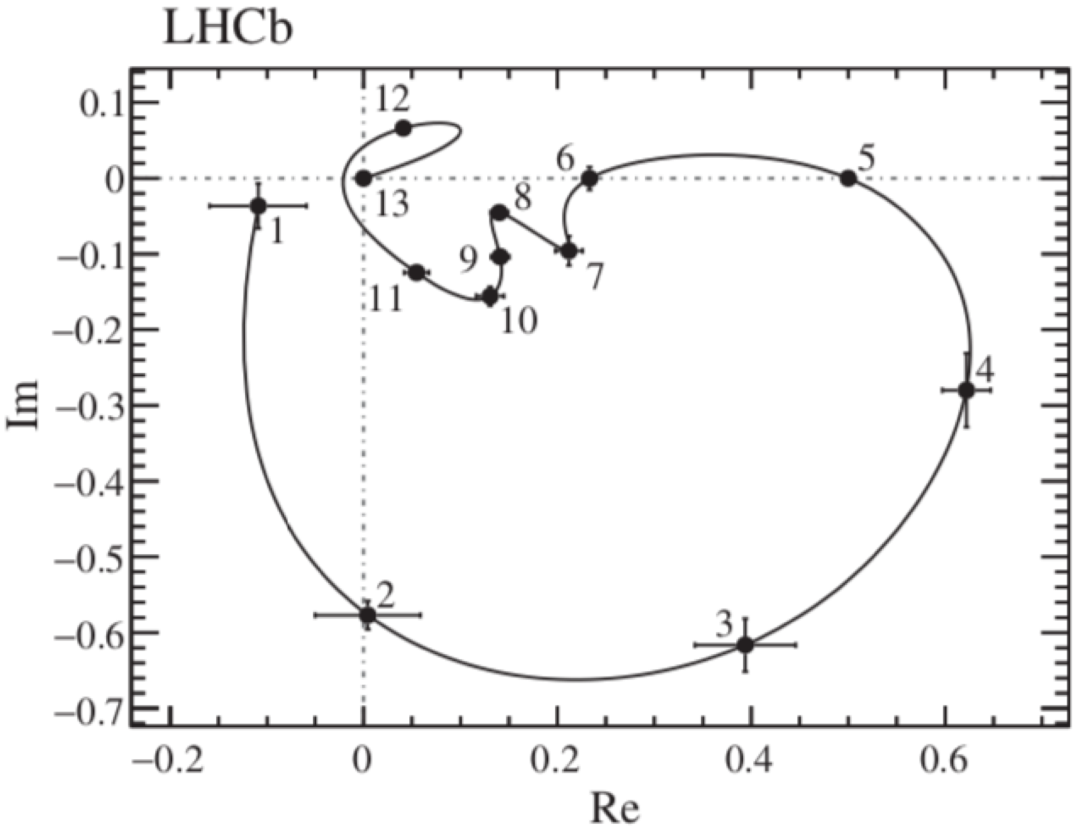
Resonance	Branching fraction (10^{-4})
$D_2^*(2460)^0$	$3.62 \pm 0.06 \pm 0.14 \pm 0.09 \pm 0.25$
$D_1^*(2680)^0$	$0.84 \pm 0.06 \pm 0.07 \pm 0.18 \pm 0.06$
$D_3^*(2760)^0$	$0.10 \pm 0.01 \pm 0.01 \pm 0.02 \pm 0.01$
$D_2^*(3000)^0$	$0.02 \pm 0.01 \pm 0.01 \pm 0.01 \pm 0.00$
$D_v^*(2007)^0$	$1.09 \pm 0.07 \pm 0.07 \pm 0.24 \pm 0.07$
B_v^*	$0.27 \pm 0.10 \pm 0.14 \pm 0.16 \pm 0.02$
Total S wave	$5.78 \pm 0.08 \pm 0.06 \pm 0.09 \pm 0.39$

Amplitude analysis of $B^- \to D^+\pi^-\pi^-$

Phys. Rev. D94 (2016) 072001

TABLE IX. Results for the $D^+\pi^-$ S-wave amplitude at the spline knots. The three quoted errors are statistical, experimental systematic and model uncertainties.

Knot mass (GeV)	$D^+\pi^-$ S wave amplitude Real part	Imaginary part
2.01	$-0.11 \pm 0.05 \pm 0.07 \pm 0.09$	$-0.04 \pm 0.03 \pm 0.05 \pm 0.11$
2.10	$0.00 \pm 0.05 \pm 0.11 \pm 0.05$	$-0.58 \pm 0.02 \pm 0.03 \pm 0.03$
2.20	$0.39 \pm 0.05 \pm 0.08 \pm 0.05$	$-0.62 \pm 0.04 \pm 0.07 \pm 0.04$
2.30	$0.62 \pm 0.02 \pm 0.03 \pm 0.01$	$-0.28 \pm 0.05 \pm 0.10 \pm 0.03$
2.40	0.50	0.00
2.50	$0.23 \pm 0.01 \pm 0.01 \pm 0.01$	$-0.00 \pm 0.02 \pm 0.04 \pm 0.01$
2.60	$0.21 \pm 0.01 \pm 0.01 \pm 0.01$	$-0.10 \pm 0.02 \pm 0.03 \pm 0.06$
2.70	$0.14 \pm 0.01 \pm 0.01 \pm 0.01$	$-0.05 \pm 0.01 \pm 0.02 \pm 0.02$
2.80	$0.14 \pm 0.01 \pm 0.01 \pm 0.01$	$-0.10 \pm 0.01 \pm 0.02 \pm 0.04$
2.90	$0.13 \pm 0.01 \pm 0.02 \pm 0.01$	$-0.16 \pm 0.01 \pm 0.02 \pm 0.02$
3.10	$0.05 \pm 0.01 \pm 0.02 \pm 0.02$	$-0.12 \pm 0.01 \pm 0.01 \pm 0.01$
4.10	$0.04 \pm 0.01 \pm 0.01 \pm 0.01$	$0.07 \pm 0.01 \pm 0.01 \pm 0.01$
5.14	0.00	0.00
	Magnitude	Phase
2.01	$0.12 \pm 0.05 \pm 0.07 \pm 0.06$	$-2.82 \pm 0.22 \pm 0.28 \pm 1.47$
2.10	$0.58 \pm 0.02 \pm 0.03 \pm 0.03$	$-1.56 \pm 0.09 \pm 0.17 \pm 0.08$
2.20	$0.73 \pm 0.01 \pm 0.03 \pm 0.02$	$-1.00 \pm 0.08 \pm 0.15 \pm 0.08$
2.30	$0.68 \pm 0.01 \pm 0.03 \pm 0.01$	$-0.42 \pm 0.08 \pm 0.14 \pm 0.05$
2.40	0.50	0.00
2.50	$0.23 \pm 0.01 \pm 0.01 \pm 0.01$	$-0.00 \pm 0.06 \pm 0.07 \pm 0.05$
2.60	$0.23 \pm 0.01 \pm 0.01 \pm 0.03$	$-0.42 \pm 0.09 \pm 0.13 \pm 0.24$
2.70	$0.15 \pm 0.01 \pm 0.01 \pm 0.01$	$-0.31 \pm 0.07 \pm 0.11 \pm 0.15$
2.80	$0.17 \pm 0.01 \pm 0.01 \pm 0.01$	$-0.63 \pm 0.08 \pm 0.10 \pm 0.19$
2.90	$0.20 \pm 0.01 \pm 0.01 \pm 0.01$	$-0.87 \pm 0.09 \pm 0.12 \pm 0.10$
3.10	$0.14 \pm 0.00 \pm 0.01 \pm 0.01$	$-1.16 \pm 0.10 \pm 0.13 \pm 0.13$
4.10	$0.08 \pm 0.00 \pm 0.01 \pm 0.01$	$1.02 \pm 0.12 \pm 0.20 \pm 0.16$
5.14	0.00	0.00



Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$

Phys. Rev. D 101 (2020) 032005

Results from the nominal model

- QMI for the $J^P = 0^-$ and 1^+ S-wave.

Resonance	J^P	fraction (%)	phase (rad)
$D_1(2420)$	1^+D	$59.8 \pm 0.3 \pm 2.9$	0
1^+S QMI	1^+S	$28.3 \pm 0.3 \pm 1.9$	$-1.19 \pm 0.01 \pm 0.15$
$D_2^*(2460)$	2^+	$15.3 \pm 0.2 \pm 0.3$	$-0.71 \pm 0.01 \pm 0.48$
$D_1(2420)$	1^+S	$2.8 \pm 0.2 \pm 0.5$	$1.43 \pm 0.02 \pm 0.31$
0^- QMI	0^-	$10.6 \pm 0.2 \pm 0.7$	$1.94 \pm 0.01 \pm 0.19$
$D_1^*(2600)$	1^-	$6.0 \pm 0.1 \pm 0.6$	$1.20 \pm 0.02 \pm 0.05$
$D_2(2740)$	2^-P	$1.9 \pm 0.1 \pm 0.4$	$-1.57 \pm 0.04 \pm 0.15$
$D_2(2740)$	2^-F	$3.2 \pm 0.2 \pm 1.1$	$1.11 \pm 0.04 \pm 0.29$
$D_3^*(2750)$	3^-	$0.35 \pm 0.04 \pm 0.05$	$-1.17 \pm 0.07 \pm 0.31$
Sum		$128.2 \pm 0.6 \pm 3.8$	

Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$

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Results from the mixing model.

Resonance	J^P	fraction (%)	phase (rad)
D_1	1^+	$58.9 \pm 0.7 \pm 2.5$	0
D_1'	1^+	$21.9 \pm 2.2 \pm 3.0$	$-1.06 \pm 0.10 \pm 0.05$
$D_2^*(2460)$	2^+	$14.0 \pm 0.2 \pm 0.3$	$2.66 \pm 0.09 \pm 0.15$
0^- QMI	0^-	$6.5 \pm 0.2 \pm 1.5$	$2.03 \pm 0.09 \pm 0.28$
$D_1^*(2600)$	1^-	$4.9 \pm 0.1 \pm 0.5$	$-2.24 \pm 0.09 \pm 0.11$
$D_2(2740)$	2^-P	$0.72 \pm 0.08 \pm 0.30$	$-2.59 \pm 0.10 \pm 0.53$
$D_2(2740)$	2^-F	$2.9 \pm 0.2 \pm 1.1$	$0.27 \pm 0.09 \pm 0.47$
$D_3^*(2750)$	3^-	$0.70 \pm 0.05 \pm 0.10$	$1.54 \pm 0.10 \pm 0.33$
Sum		$110.4 \pm 2.3 \pm 4.4$	

Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$

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Summary of the measurements of the branching fractions.

Resonance	J^P	$\mathcal{B}(B^- \to R^0\pi^-) \times \mathcal{B}(R^0 \to D^{*+}\pi^-) \times 10^{-4}$	
		This analysis	Belle collaboration
$D_1(2420)$	1^+	$8.42 \pm 0.08 \pm 0.40 \pm 1.40$	
$D_1(2430)$	1^+S	$3.51 \pm 0.06 \pm 0.23 \pm 0.57$	
$D_2^*(2460)$	2^+	$2.08 \pm 0.03 \pm 0.14 \pm 0.34$	$1.8 \pm 0.3 \pm 0.3 \pm 0.2$
$D_0(2550)$	0^-	$0.72 \pm 0.01 \pm 0.07 \pm 0.12$	
$D_1^*(2600)$	1^-	$0.68 \pm 0.01 \pm 0.07 \pm 0.11$	
$D_2(2740)$	2^-	$0.33 \pm 0.02 \pm 0.14 \pm 0.05$	
$D_3^*(2750)$	3^-	$0.11 \pm 0.01 \pm 0.02 \pm 0.02$	
D_1	1^+	$7.95 \pm 0.09 \pm 0.34 \pm 1.30$	$6.8 \pm 0.7 \pm 1.3 \pm 0.3$
D_1'	1^+	$2.96 \pm 0.30 \pm 0.41 \pm 0.48$	$5.0 \pm 0.4 \pm 1.0 \pm 0.4$

Amplitude analysis of $B^- \to D^{*+}\pi^-\pi^-$

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Comparison of the resonant parameters with previous measurements.

Resonance	J^P	Decays	Mass [MeV]	Width [MeV]	References
$D_0(2550)^0$	0^-	$D^{*+}\pi^-$	$2518 \pm 2 \pm 7$	$199 \pm 5 \pm 17$	This work
$D_J(2550)^0$		$D^{*+}\pi^-$	$2539.4 \pm 4.5 \pm 6.8$	$130 \pm 12 \pm 13$	BaBar [11]
$D_J(2580)^0$		$D^{*+}\pi^-$	$2579.5 \pm 3.4 \pm 3.5$	$177.5 \pm 17.8 \pm 46.0$	LHCb [12]
$D_1^*(2600)^0$	1^-	$D^{*+}\pi^-$	$2641.9 \pm 1.8 \pm 4.5$	$149 \pm 4 \pm 20$	This work
$D_J^*(2600)^0$		$D^+\pi^-$	$2608.7 \pm 2.4 \pm 2.5$	$93 \pm 6 \pm 13$	BaBar [11]
$D_J^*(2650)^0$		$D^{*+}\pi^-$	$2649.2 \pm 3.5 \pm 3.5$	$140.2 \pm 17.1 \pm 18.6$	LHCb [12]
$D_1^*(2680)^0$		$D^+\pi^-$	$2681.1 \pm 5.6 \pm 4.9$	$186.7 \pm 8.5 \pm 8.6$	LHCb [14]
$D_2(2740)^0$	2^-	$D^{*+}\pi^-$	$2751 \pm 3 \pm 7$	$102 \pm 6 \pm 26$	This work
$D_J(2750)^0$		$D^{*+}\pi^-$	$2752.4 \pm 1.7 \pm 2.7$	$71 \pm 6 \pm 11$	BaBar [11]
$D_J(2740)^0$		$D^{*+}\pi^-$	$2737.0 \pm 3.5 \pm 11.2$	$73.2 \pm 13.4 \pm 25.0$	LHCb [12]
$D_3^*(2750)^0$	3^-	$D^{*+}\pi^-$	$2753 \pm 4 \pm 6$	$66 \pm 10 \pm 14$	This work
$D_J^*(2760)^0$		$D^{*+}\pi^-$	$2761.1 \pm 5.1 \pm 6.5$	$74.4 \pm 3.4 \pm 37.0$	LHCb [12]
		$D^+\pi^-$	$2760.1 \pm 1.1 \pm 3.7$	$74.4 \pm 3.4 \pm 19.1$	LHCb [12]
		$D^+\pi^-$	$2763.3 \pm 2.3 \pm 2.3$	$60.9 \pm 5.1 \pm 3.6$	BaBar [11]
$D_J^*(2760)^+$		$D^0\pi^+$	$2771.7 \pm 1.7 \pm 3.8$	$66.7 \pm 6.6 \pm 10.5$	LHCb [12]
$D_3^*(2760)^+$	3^-	$D^0\pi^-$	$2798 \pm 7 \pm 1$	$105 \pm 18 \pm 6$	LHCb [13]
$D_3^*(2760)^0$	3^-	$D^+\pi^-$	$2775.5 \pm 4.5 \pm 4.5$	$95.3 \pm 9.6 \pm 7.9$	LHCb [14]