Current challenges and future prospects for measuring γ from b-hadron → Dhh' decays

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on behalf of the LHCb collaboration

CKM2016, 1st December 2016

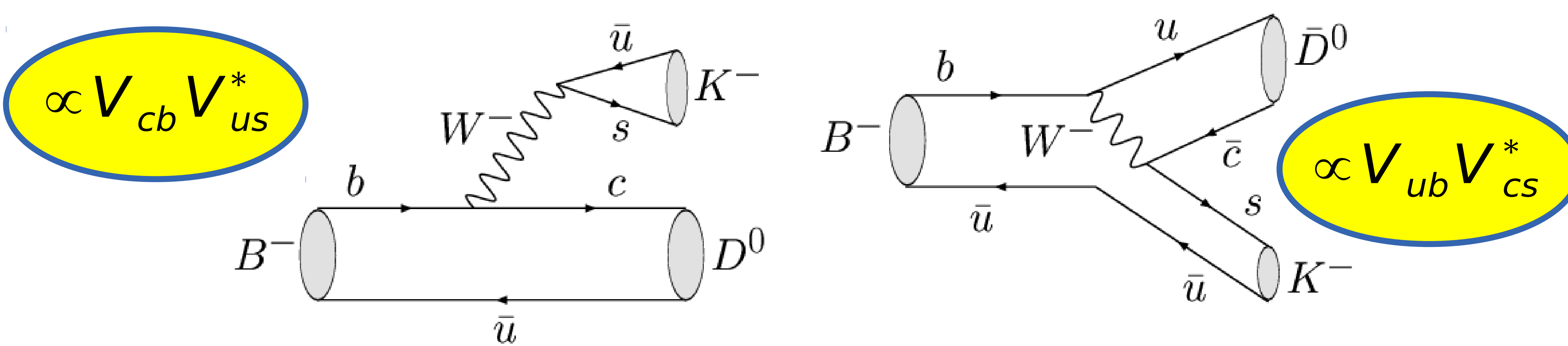
Importance of γ from B→DK(π)

- γ plays a unique role in flavour physics

the only CP violating parameter that can be measured through tree decays (*)

(*) more-or-less

- A benchmark Standard Model reference point
  - doubly important after New Physics is observed



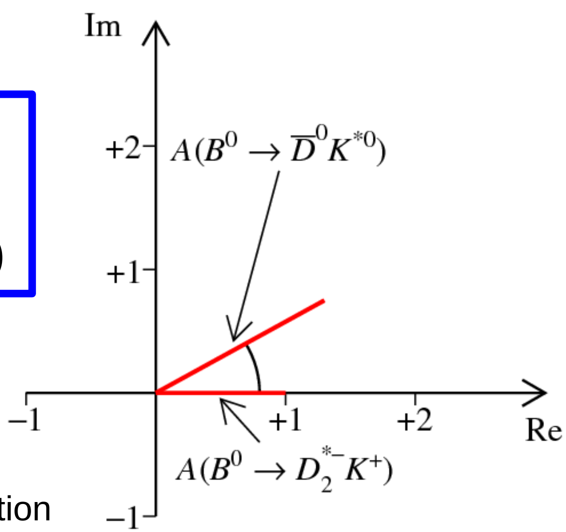
Variants use different B or D decays
require a final state common to both D^0 and $\overline{D}^0$

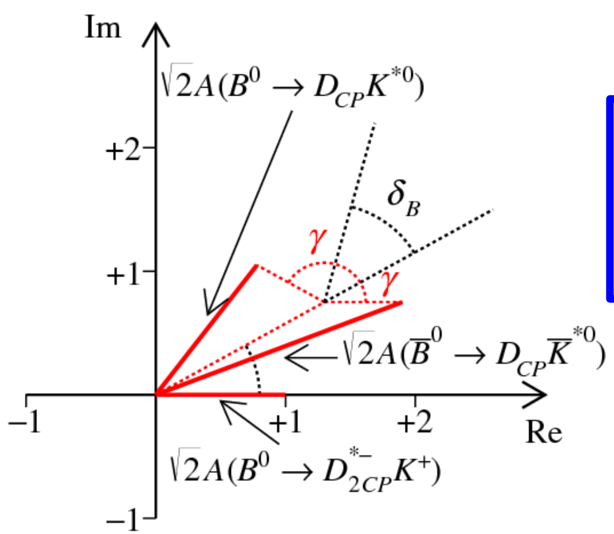
Power of Dalitz plot analyses

- Interference between resonances in a Dalitz plot (DP) provides additional sensitivity to relative phases
  - avoid quasi-two-body (Q2B) assumption that introduces hadronic parameters
- Example: $B^0 \rightarrow DK^+\pi^-$ (PR D79 (2009) 051301, D80 (2009) 092002)

$D \rightarrow K\pi$
($b \rightarrow c$ amplitude only)

approximation for illustration (suppressed contribution can also be included)





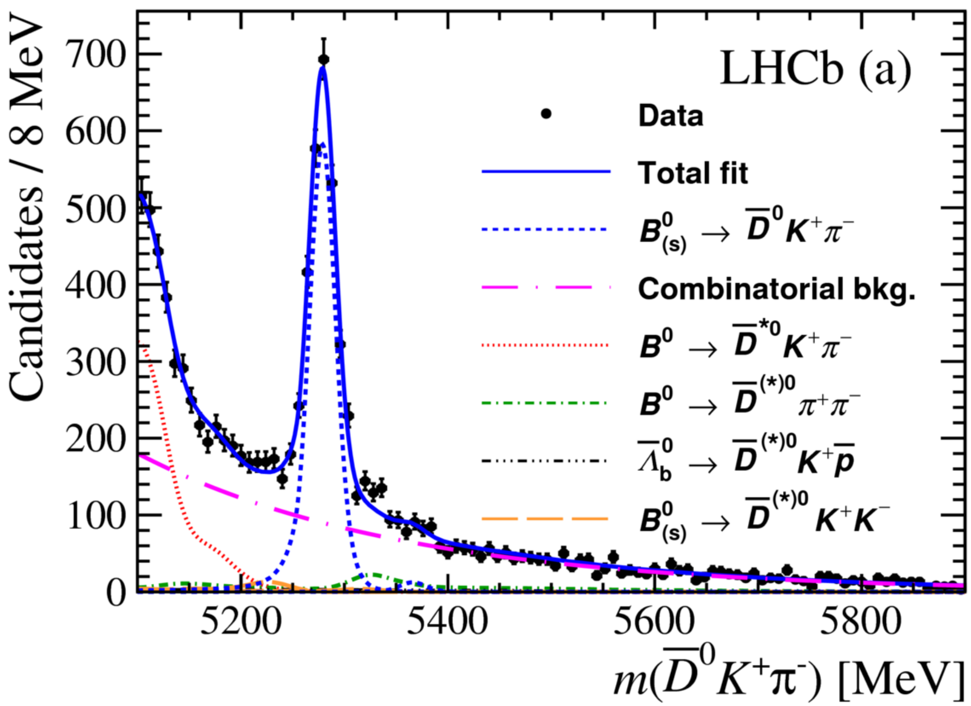
$D \rightarrow KK,\pi\pi$
($b \rightarrow c$ and $b \rightarrow u$ amplitudes)

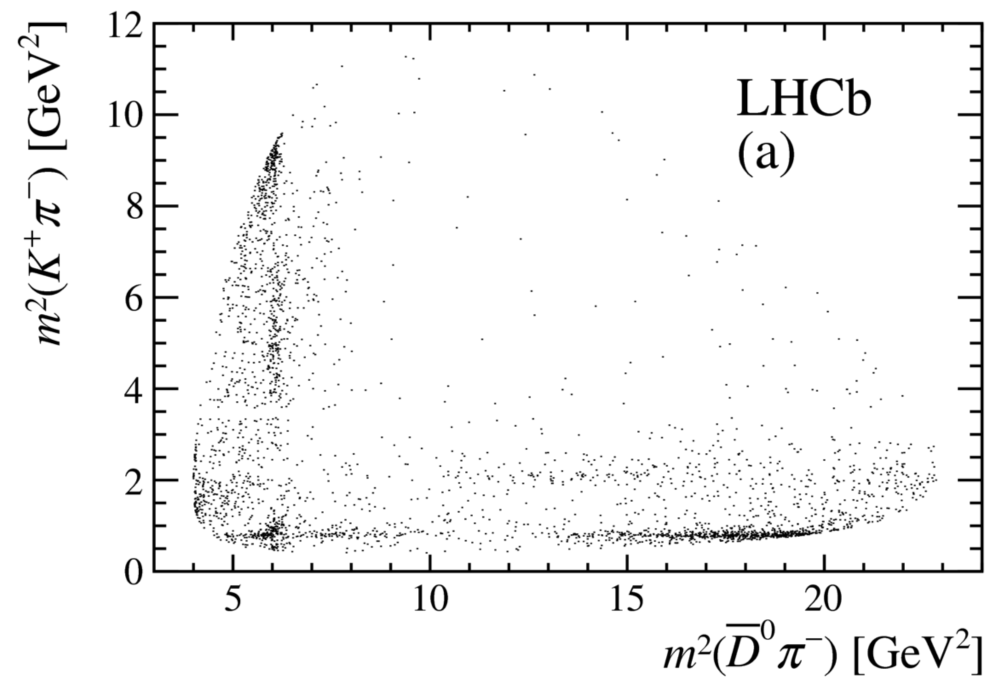
Key point is that $D_2^{*-}K^+$ amplitude is flavour-tagged and therefore identical in all final states

Dalitz plot analysis of $B^0 \to \overline{D}^0 K^+ \pi^-$

PR D92 (2015) 012012

- Treating $\overline{D}^0 \to K^+\pi^-$ decays as flavour-specific



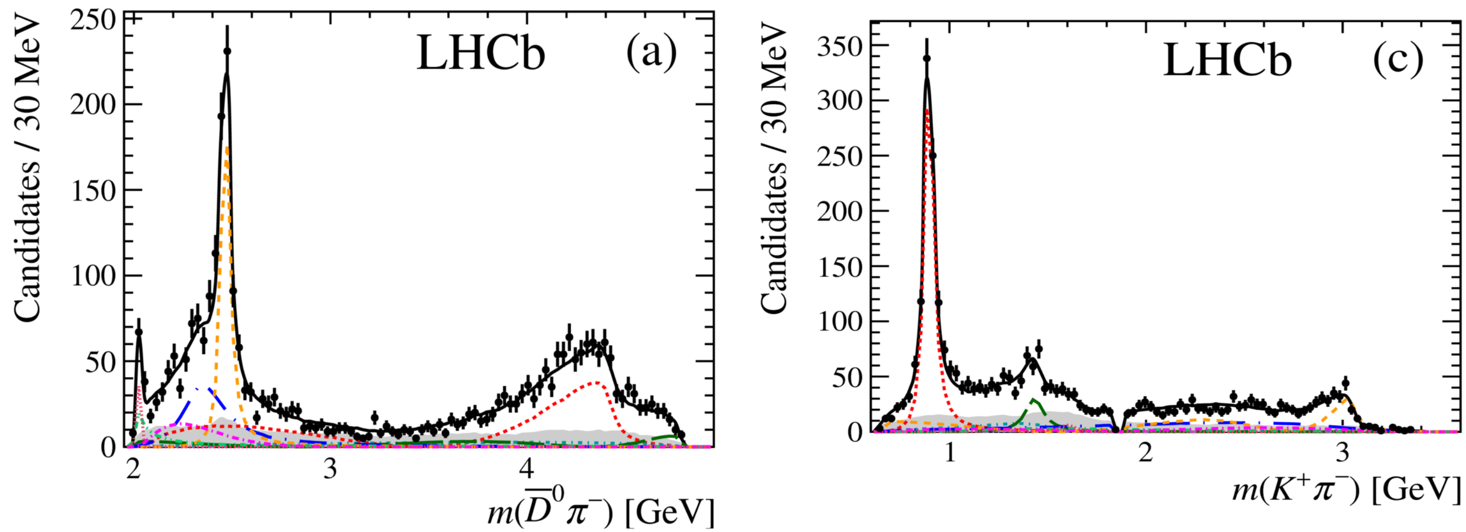


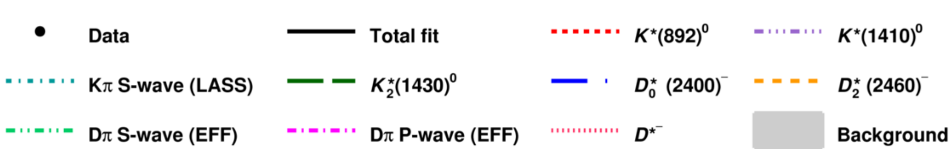
Using LHCb Run I data (3/fb)
2344 ± 66 decays
in B^0 signal region

Dalitz plot analysis of $B^0 \to \overline{D}{}^0 K^+ \pi^-$

PR D92 (2015) 012012

- Treating $\overline{D}{}^0 \to K^+\pi^-$ decays as flavour-specific





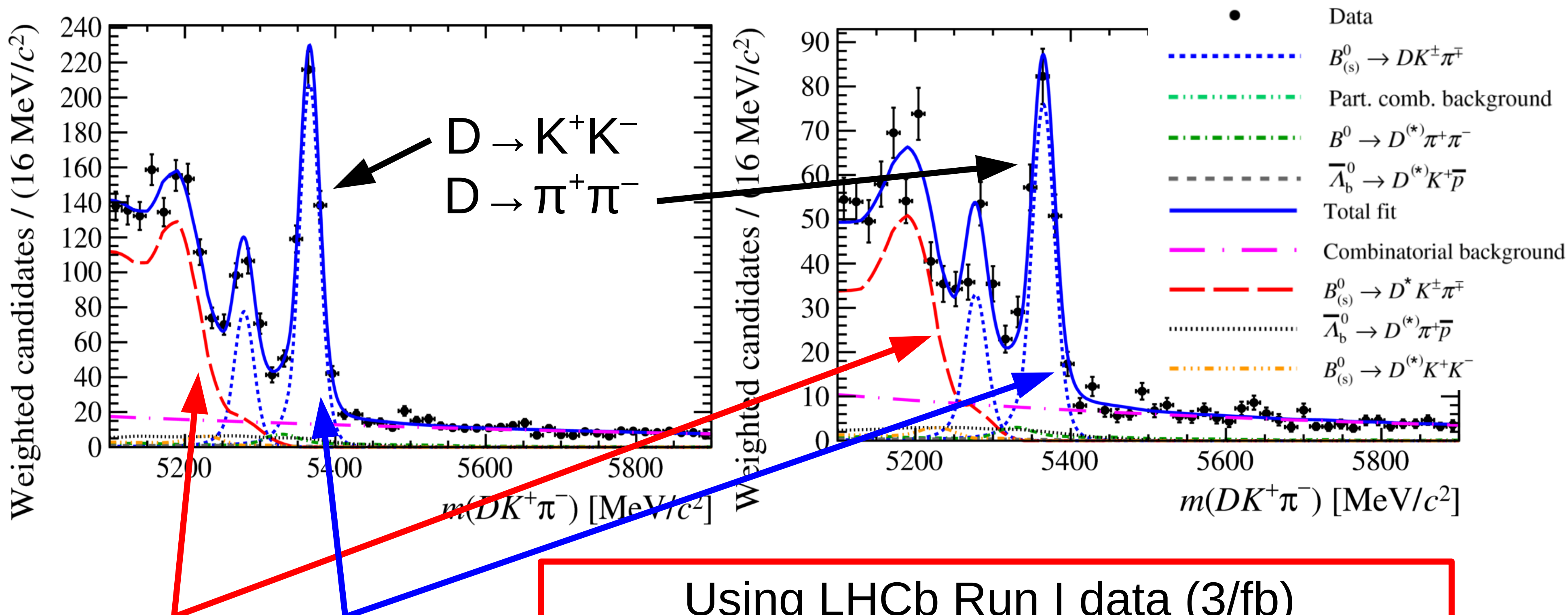
Resonance	Fit fraction	Upper limit
$K^*(892)^0$	$37.4 \pm 1.5 \pm 1.2 \pm 1.7$	
$K^*(1410)^0$	$0.7 \pm 0.3 \pm 0.8 \pm 0.8$	< 3.2 (3.7)
$K_0^*(1430)^0$	$5.1 \pm 2.0 \pm 2.4 \pm 3.4$	
LASS nonresonant	$4.8 \pm 3.8 \pm 3.8 \pm 6.7$	
LASS total	$6.7 \pm 2.7 \pm 2.7 \pm 5.4$	
$K_2^*(1430)^0$	$7.4 \pm 1.7 \pm 1.1 \pm 2.0$	
$D_0^*(2400)^-$	$19.3 \pm 2.8 \pm 2.0 \pm 7.4$	
$D_2^*(2460)^-$	$23.1 \pm 1.2 \pm 1.1 \pm 1.2$	
$D_3^*(2760)^-$		< 1.0 (1.1)
$D\pi$ S-wave (dabba)	$6.6 \pm 1.4 \pm 1.2 \pm 3.7$	
$D\pi$ P-wave (EFF)	$8.9 \pm 1.6 \pm 2.2 \pm 3.0$	

Masses and widths also measured

Dalitz plot analysis of $B^0 \to DK^+\pi^-$

PR D93 (2016) 112018

- Simultaneous DP fit to $D \to K^+\pi^-$, K^+K^-, $\pi^+\pi^-$



$B_s^0 \to D^*K\pi$ / $DK\pi$ backgrounds

Using LHCb Run I data (3/fb)
339 ± 22 / 168 ± 19 K^+K^- / $\pi^+\pi^-$ decays
in B^0 signal region

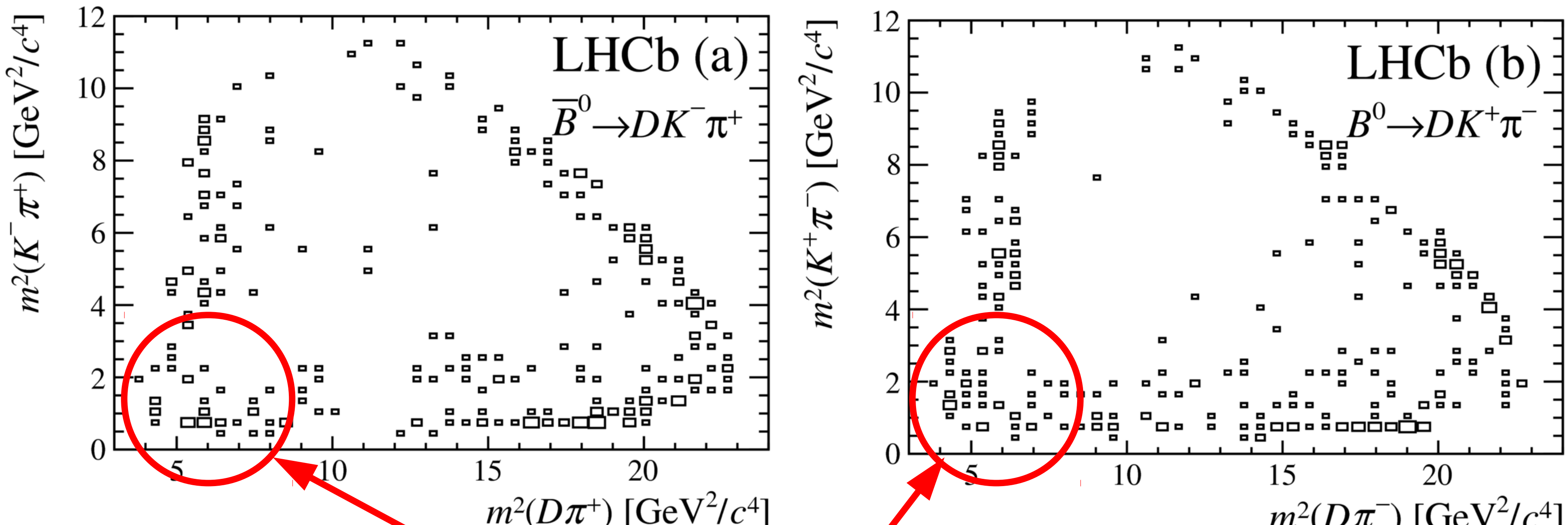
γ from $B^0 \to DK^+\pi^-$

PR D93 (2016) 112018

- Simultaneous DP fit to $D \to K^+\pi^-$, K^+K^-, $\pi^+\pi^-$

  [technical detail: simultaneous fit using Laura++ (arXiv:1603.00752) with *jFit* method (arXiv:1409.5080)]

  – (Dπ) resonance amplitudes same for $D \to K^+\pi^-$, K^+K^-, $\pi^+\pi^-$
  – (Kπ) amplitudes modified for $D \to K^+K^-$, $\pi^+\pi^-$: sensitivity to γ

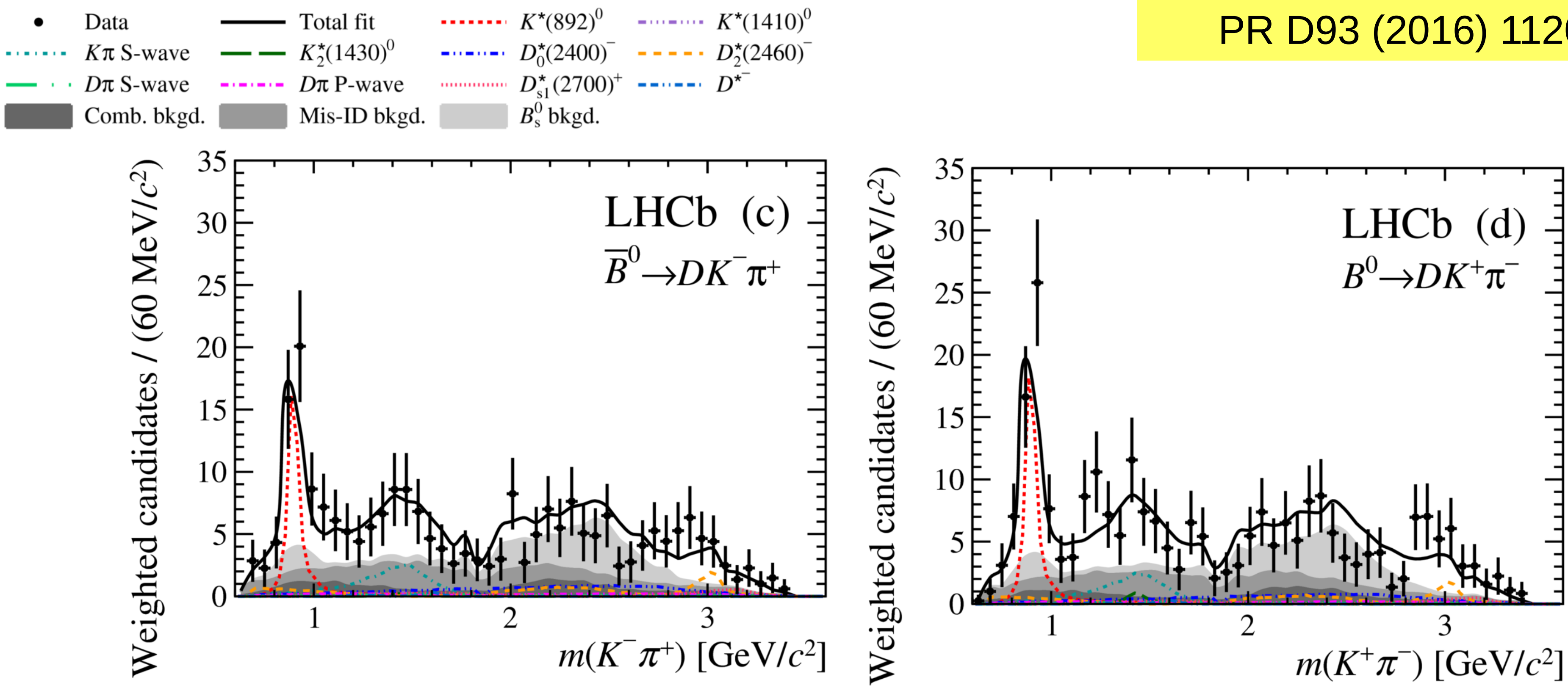


$D \to KK$, $\pi\pi$

Interference effects in the D_2^{*-}–K^{*0} overlap region enhance sensitivity to γ

γ from $B^0 \to DK^+\pi^-$

PR D93 (2016) 112018



$D \to KK, \pi\pi$

Projections contain only partial information from the Dalitz plot analysis

… but no clear asymmetry in $B^0 \to DK^*(892)^0$

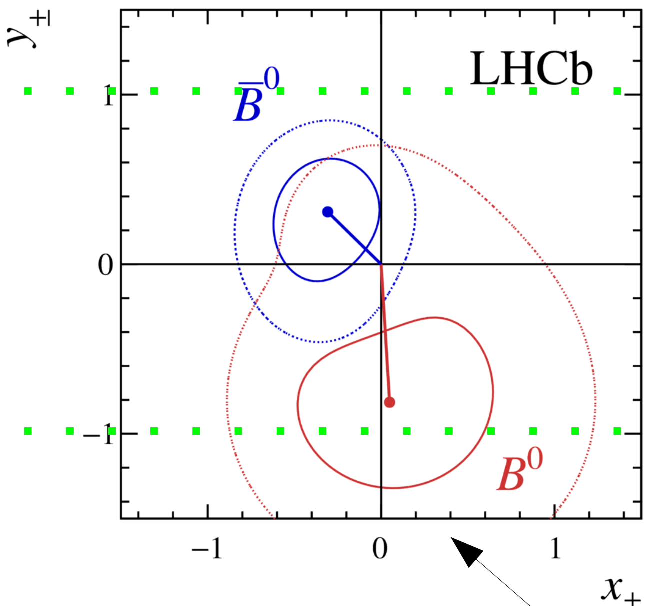
… results consistent with Q2B GLW analysis (PR D90 (2014) 112002)

γ from $B^0 \to DK^{*0}$ Q2B & DP

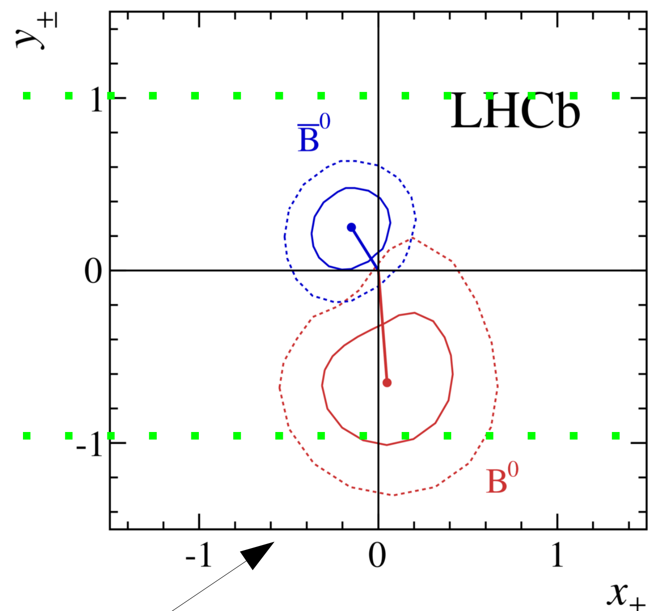
JHEP 06 (2016) 131

JHEP 08 (2016) 137

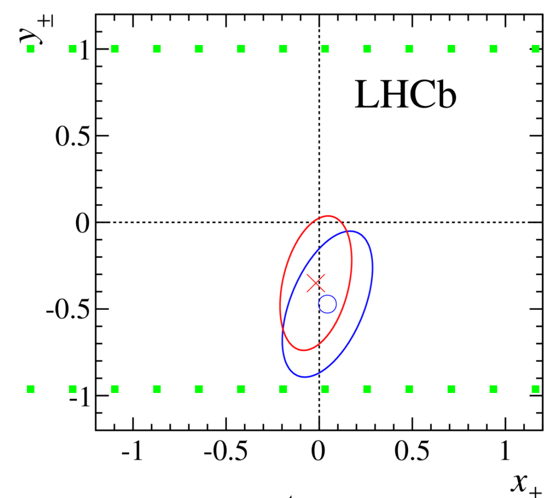
PR D93 (2016) 112018



model-independent



model-dependent



$B^0 \to DK^{*0}$ Q2B
$D \to K_S\pi\pi$

$B^0 \to DK\pi$ DP analysis
$D \to KK,\pi\pi$

Comparison of results in terms of $x_\pm = r_B\cos(\delta_B \pm \gamma)$, $y_\pm = r_B\sin(\delta_B \pm \gamma)$

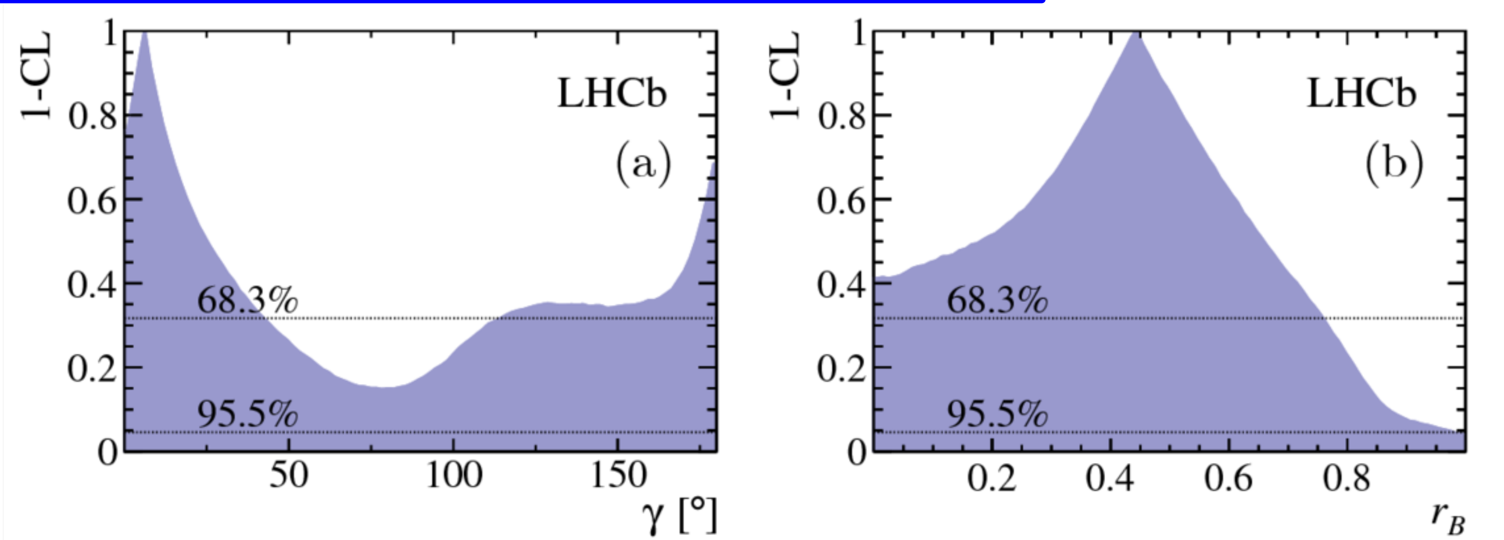
RED: (x_+,y_+), BLUE (x_-,y_-)

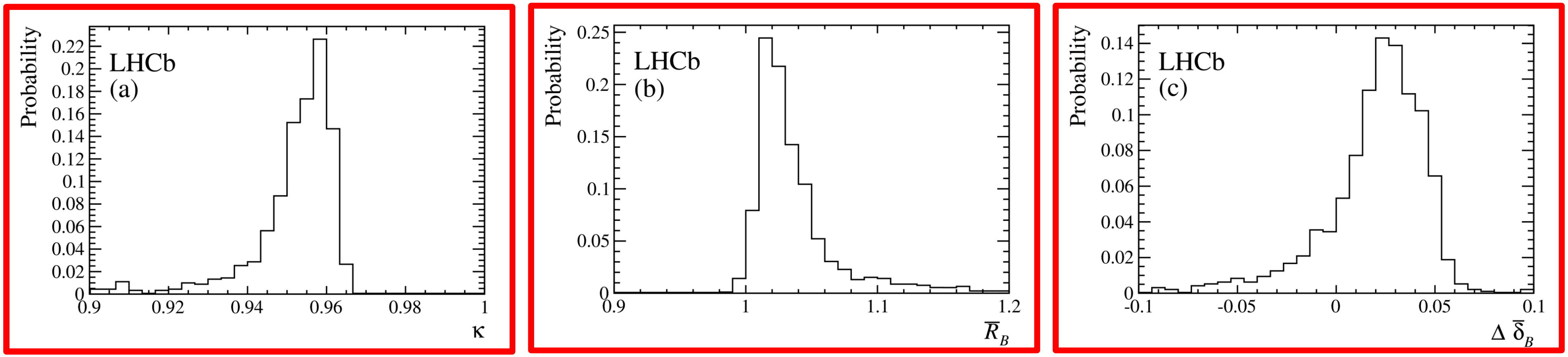
two modes consistent at 2σ level

γ from $B^0 \to DK^{*0}$ from DP analysis

"unlucky" central values of $(x_\pm, y_\pm)$ → limited precision on γ

PR D93 (2016) 112018





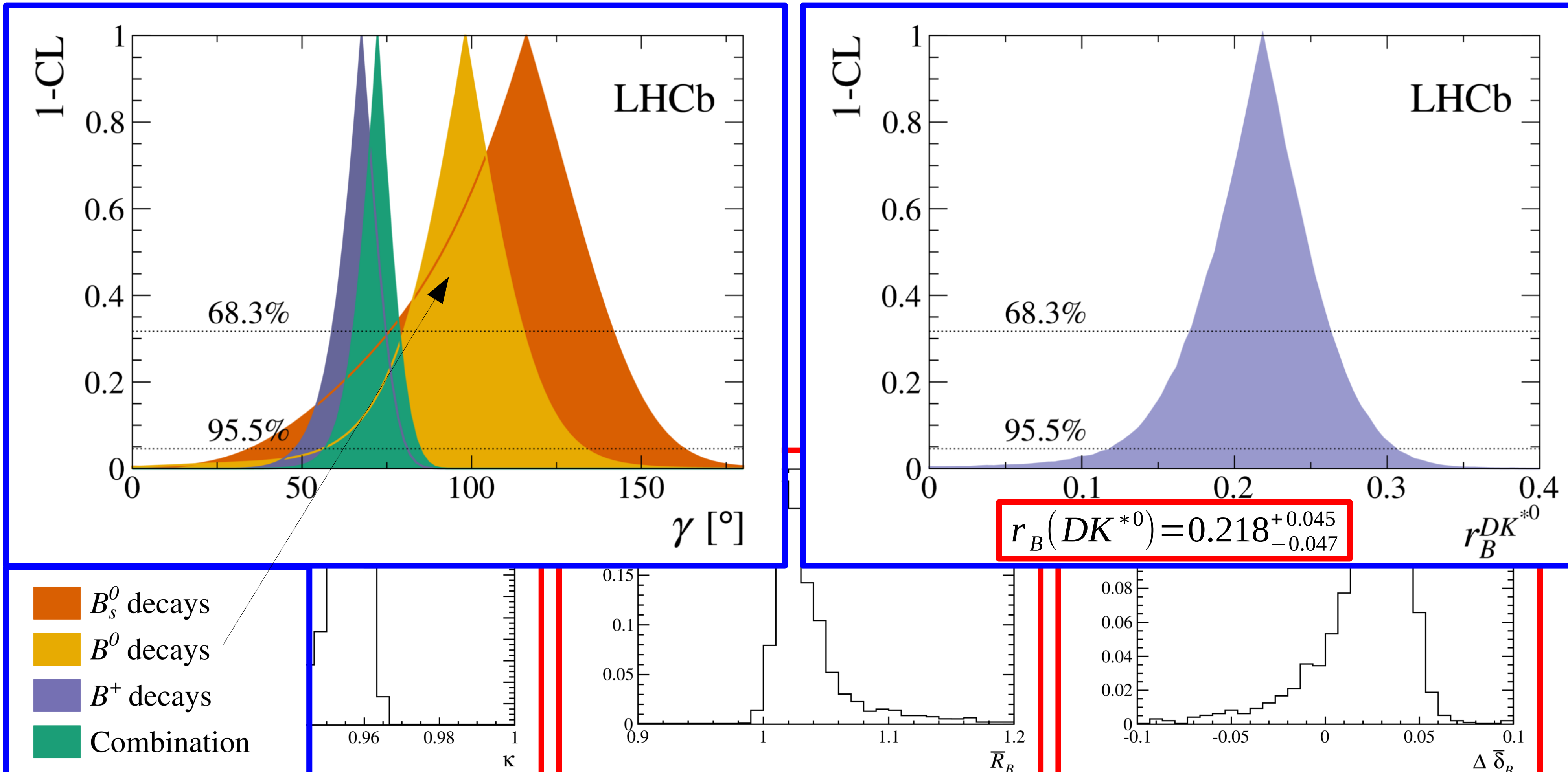
Obtain also hadronic parameters needed to relate results from quasi-two-body analysis to pure $B^0 \to DK^*(892)^0$

See talk by F. Machefert for details

γ from $B^0 \to DK^{*0}$ (combined)

still an important impact on overall combination

arXiv:1611.03076



Obtain also hadronic parameters needed to relate results from quasi-two-body analysis to pure $B^0 \to DK^*(892)^0$

Prospects for γ from $B^0 \to DK^+\pi^-$

- Reduce statistical uncertainties
  - Run II data taking going very well; excellent long term prospects
- Reduce model uncertainty
  - Develop better understanding of Kπ & Dπ S-waves
  - Work ongoing (e.g. $B^+ \to D^-\pi^+\pi^+$ Dalitz plot analysis; PR D94 (2016) 072001)
- Control background from $B_s^0 \to D^{(*)}K^-\pi^+$ decays
  - $B_s^0 \to \overline{D}{}^0K^-\pi^+$ DP analysis already done (PRL 113 (2014) 162001; PR D90 (2014) 072003)
  - Study $B_s^0 \to \overline{D}{}^{*0}K^-\pi^+$ directly; also investigate $B_s^0 \to D^-K^-\pi^+\pi^+$ decays
- Add more D modes
  - Inclusion of ADS $D \to K\pi$ requires good control of B_s^0 background
    - will improve sensitivity and enable best control of suppressed amplitude contributions
  - Inclusion of $D \to K_S\pi^+\pi^-$ possible with "double Dalitz plot analysis" (PR D81 (2010) 014025)

Other $b \to Dhh'$ modes

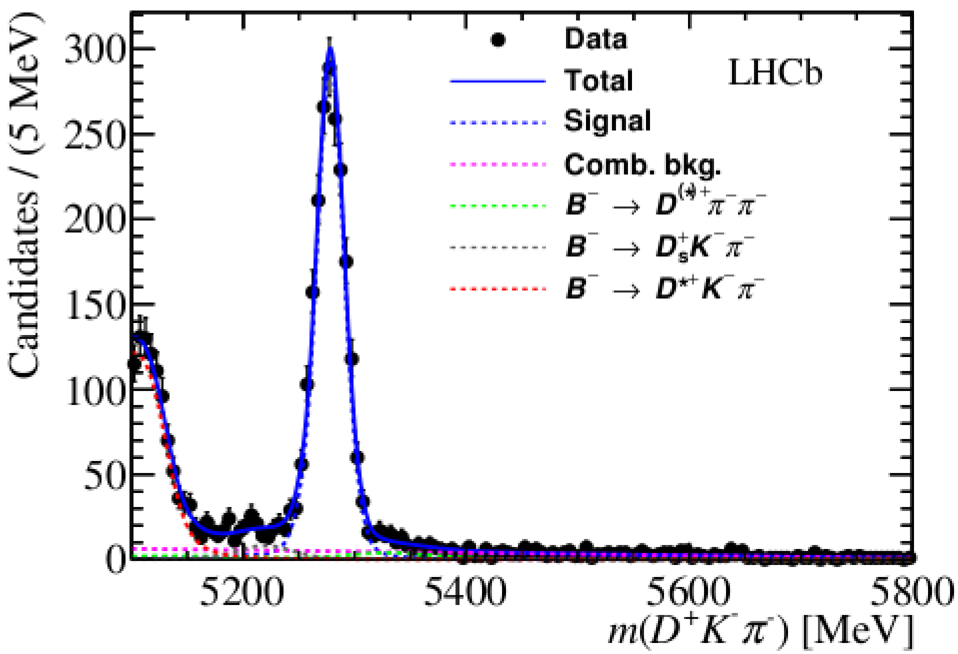
- How about isospin partner: $B^+ \to DK^+\pi^0$? Experimentally challenging but worthwhile?
- Challenge:
  - $(D\pi)$ resonances now not flavour tagged $\to$ require more complicated formalism compared to $B^0 \to DK^+\pi^-$
- Possible benefit:
  - More interference between $b \to u$ & $b \to c$ amplitudes $\to$ more sensitivity to γ
- Extra information:
  - Relative magnitude (r_B) of $b \to u$ & $b \to c$ amplitudes in $(D\pi)$ resonances can be known from $B^+ \to D^+K^+\pi^-$ and $B^+ \to D^-K^+\pi^+$ decays (N. Sinha PR D70 (2004) 097501)
- Previous work:
  - Same channel investigated by Aleksan, Petersen & Soffer (PR D67 (2003) 096002), but with assumptions that are now known to be too simplistic

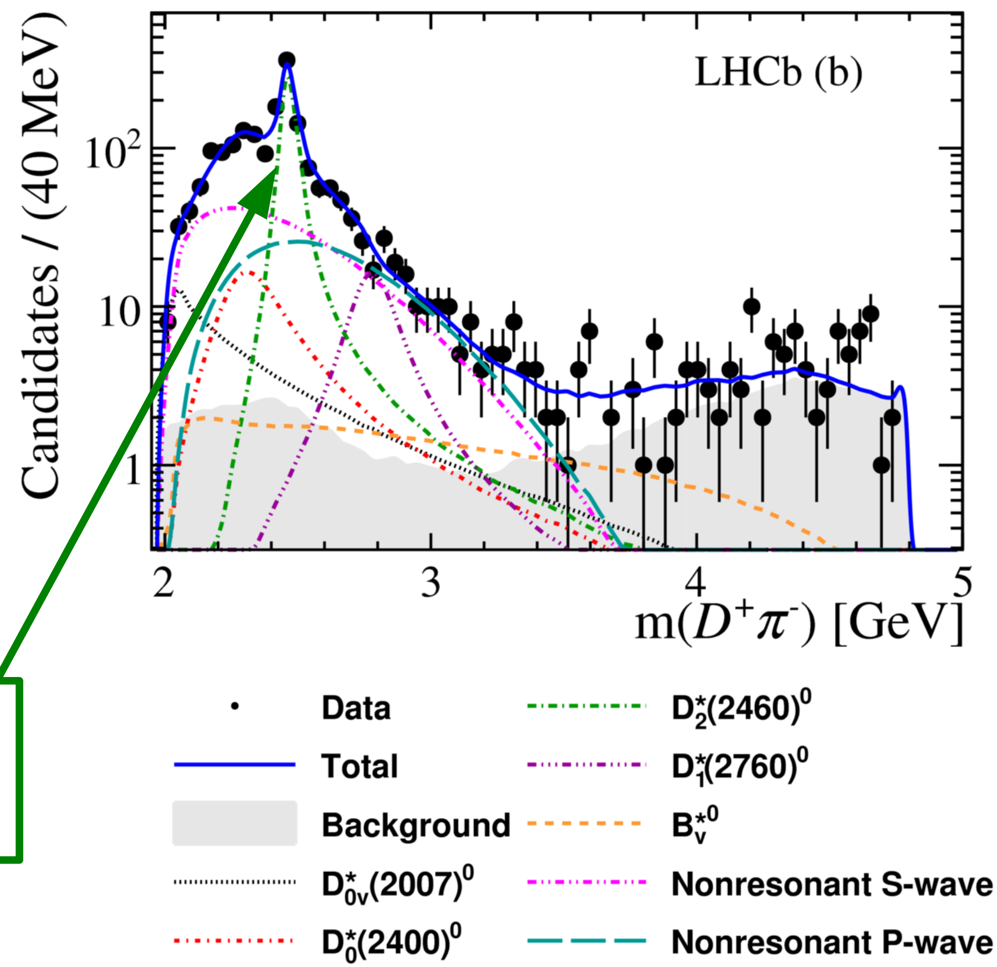
Requires a careful study – see talk by TG at ICHEP2016

$B^+ \to D^+K^+\pi^-$ and $B^+ \to D^-K^+\pi^+$ decays

PR D91 (2015) 092002, PR D93 (2016) 051101

- Recent first observations of both modes by LHCb



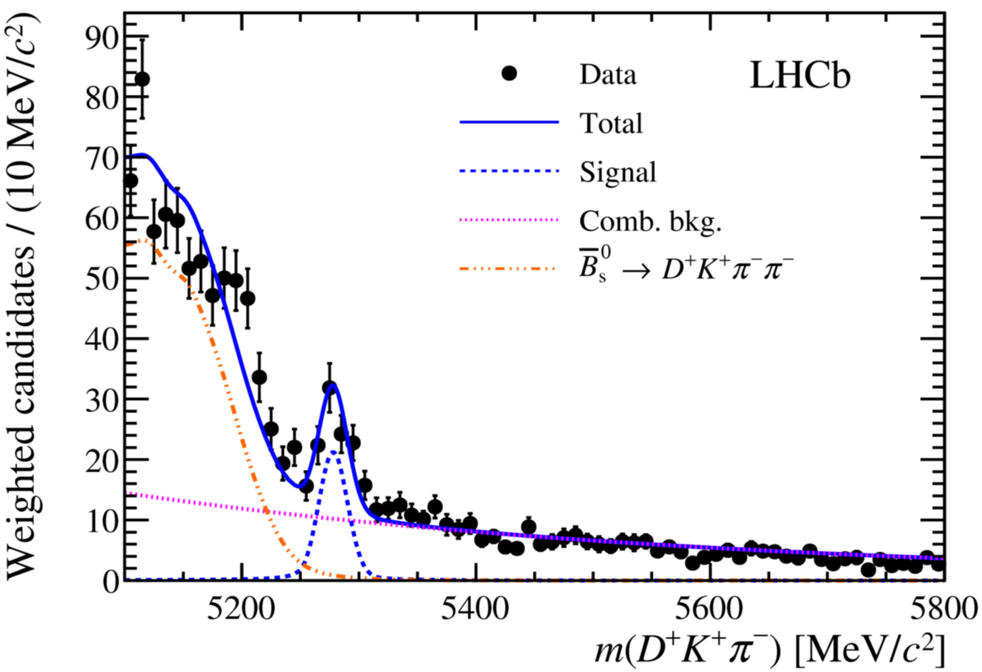


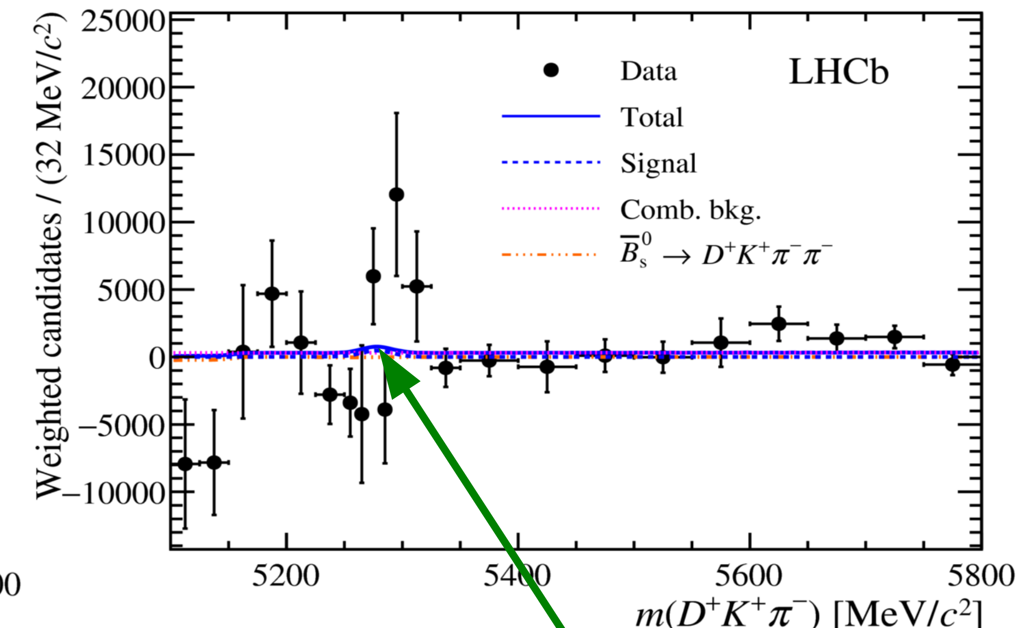
Large $D_2^*(2460)^0$ component in favoured mode

$B^+ \to D^+K^+\pi^-$ and $B^+ \to D^-K^+\pi^+$ decays

PR D91 (2015) 092002, PR D93 (2016) 051101

- Recent first observations of both modes by LHCb





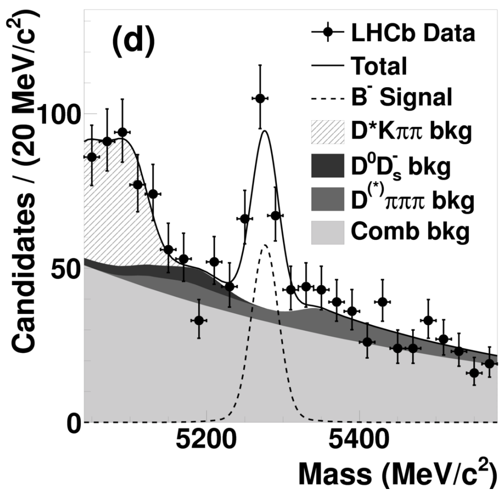
$r_B(D_2^*(2460)^0K^+) = 0.04 \pm 0.18$ (stat) $\pm\ 0.06$ (syst)
$< 0.30\ (0.36)$ @ 90 (95) % CL

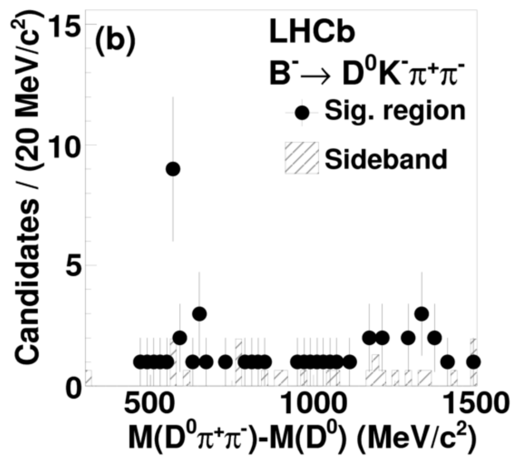
Angular-moment-weighted data show no $D_2^*(2460)^0$ component in suppressed mode

$B^+ \to DK^+\pi^+\pi^-$ decays

PRL 108 (2012) 161801

- Apply similar ideas to four-body final state?



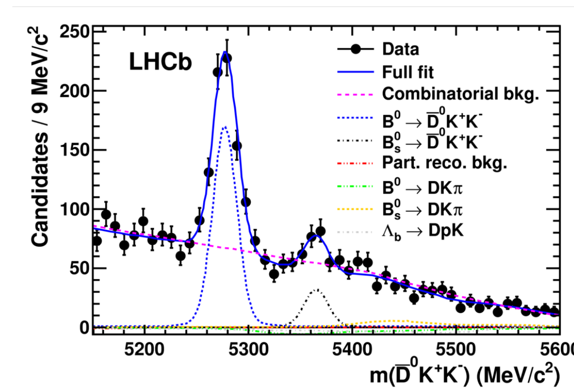


- Possible contribution from $\overline{D}_1(2420)^0K^+$ seen with 35/pb of data
  - Decays $D_1(2420) \to D^*\pi$ and $D(\pi\pi)$ allow interference between flavour-tagged and untagged D mesons in same final state
- $B^+ \to DK_1^+ \to DK^+\pi^+\pi^-$ also sensitive to γ (PR D92 (2015) 112005)

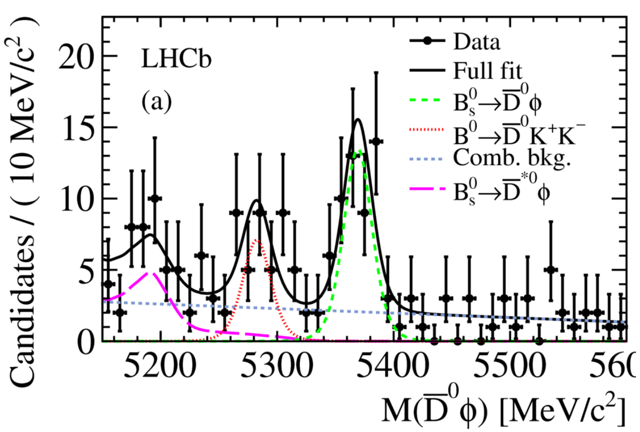
$B_s^0 \to DK^+K^-$ decays

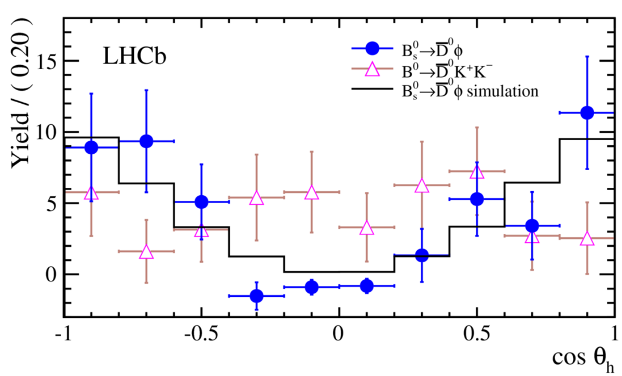
PRL 109 (2012) 131801; PL B727 (2013) 403

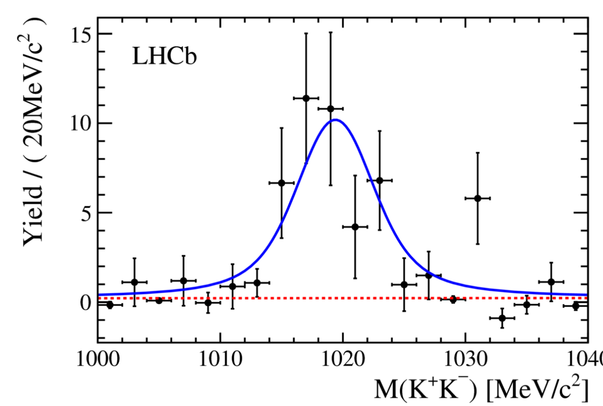
- Full analysis requires flavour-tagging → less sensitive
- Evidence for three-body $B_s^0 \to \overline{D}{}^0 K^+K^-$ decay in 0.62/fb



- Observation of $B_s^0 \to \overline{D}{}^0 \phi$ in 3/fb



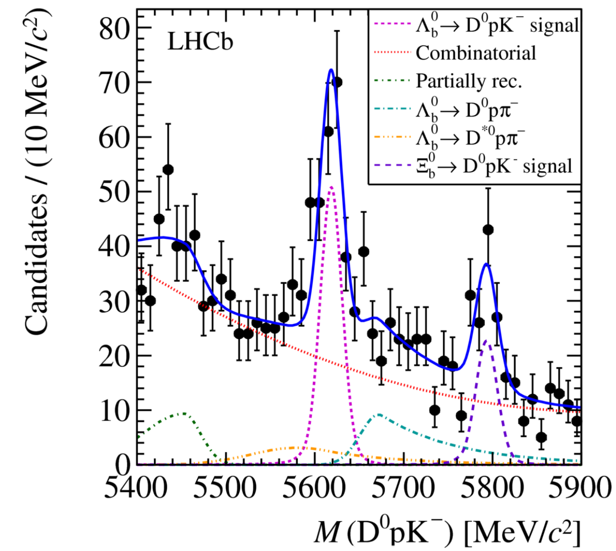


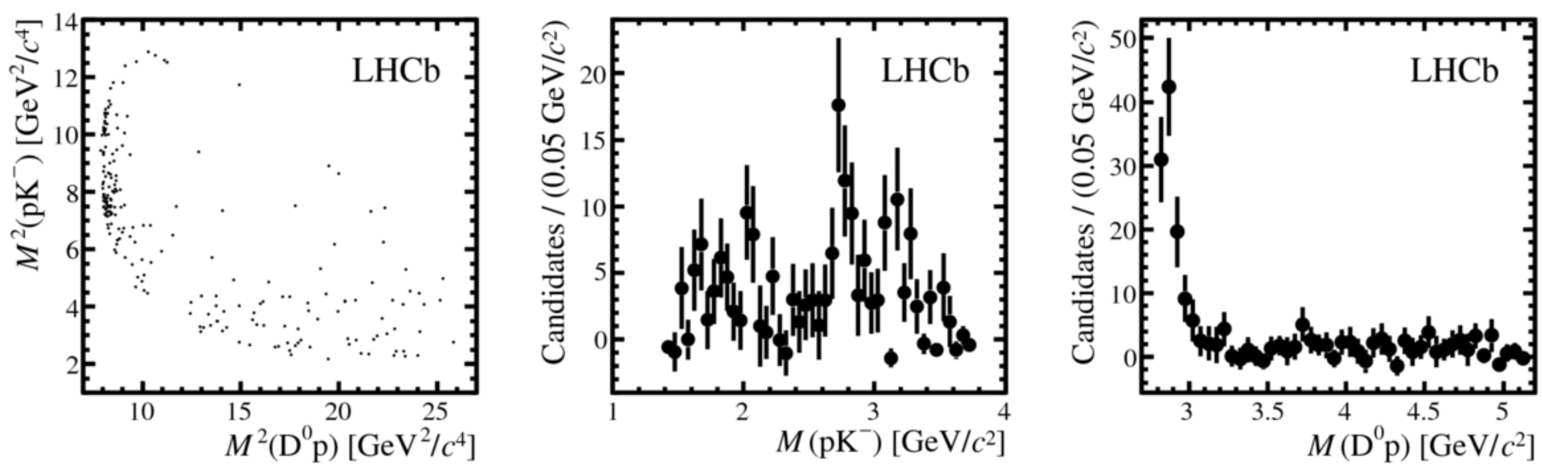


$\Lambda_b^0 \rightarrow DpK^-$ decays

PR D89 (2014) 032001

- $\Lambda_b^0 \rightarrow D^0pK^-$ decay observed in 1/fb
  - signal yield of 163 ± 18
- Kinematics limits overlap between (Dp) and (pK) resonances
  - gain relative to Q2B analysis unclear





Summary

- b-hadron $\rightarrow$ Dhh' decays provide many interesting ways to determine γ
  - Dalitz plot analysis methods particularly sensitive
- Results from $B^0 \rightarrow DK^{*0}$ give competitive sensitivity to those from $B^+ \rightarrow DK^+$
  - Precision will improve more as further D modes added
  - Will be interesting to see how central value of $r_B(DK^{*0})$ evolves
- Other b-hadron $\rightarrow$ Dhh' modes well worth pursuing
  - Strong impact on γ unlikely (now a precision measurement)
  - May find surprises (also in hadronic/spectroscopy aspects)


BACK UP!

Dalitz plot analysis of $B^0 \to \overline{D}^0 K^+ \pi^-$

PR D92 (2015) 012012

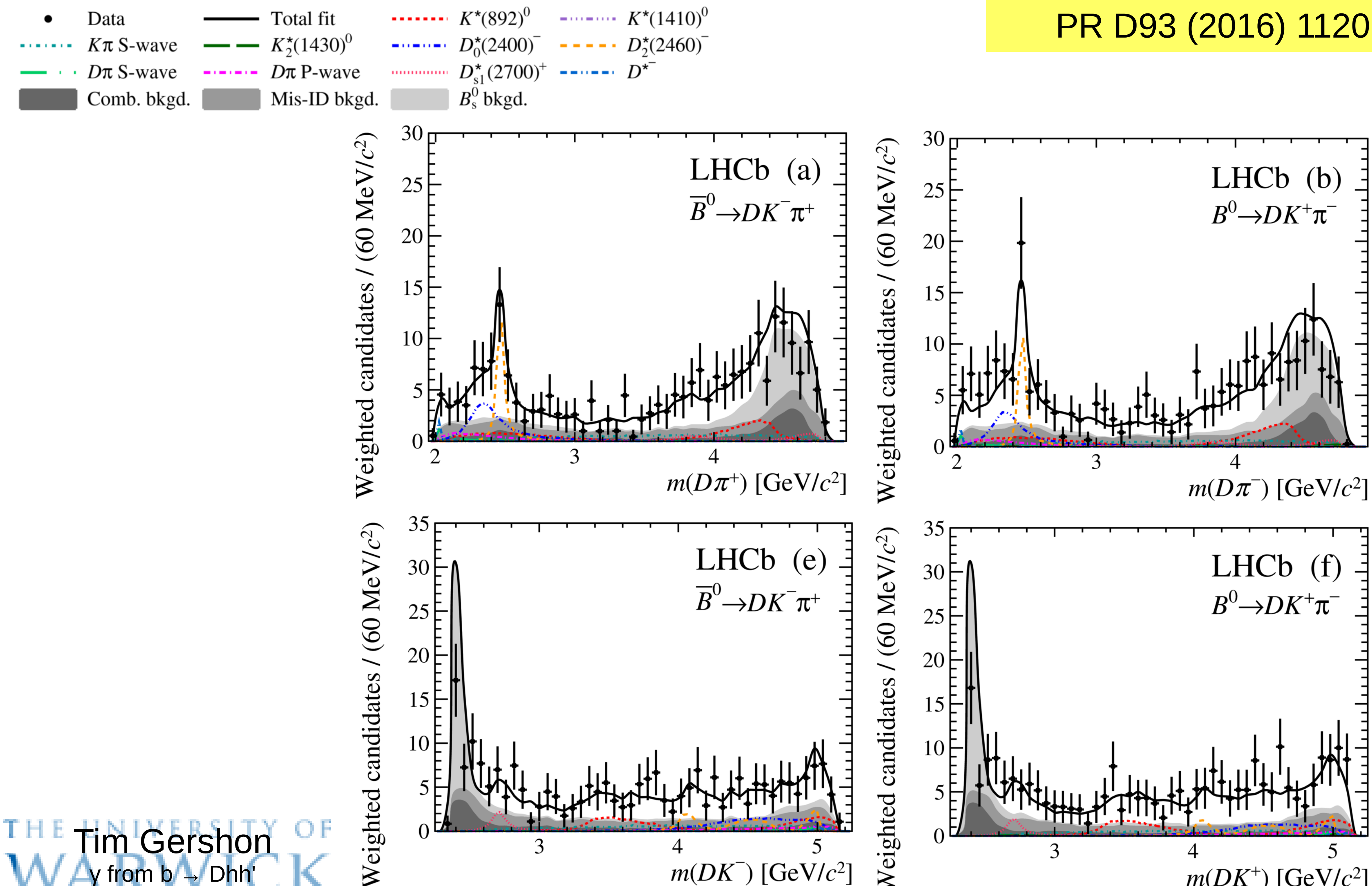
Breakdown of experimental systematic and model uncertainties

Resonance	Central value	S/B fraction	Efficiency	Background SDP	Fit bias	Total
$K^*(892)^0$	37.4 ± 1.5	0.60	0.83	0.50	0.31	1.17
$K^*(1410)^0$	0.7 ± 0.3	0.06	0.39	0.69	0.05	0.80
$K_0^*(1430)^0$	5.1 ± 2.0	0.28	1.48	1.85	0.33	2.41
LASS nonresonant	4.8 ± 3.8	0.51	2.25	2.86	0.86	3.77
LASS total	6.7 ± 2.7	0.26	1.86	1.60	1.02	2.67
$K_2^*(1430)^0$	7.4 ± 1.7	0.23	0.72	0.53	0.54	1.07
$D_0^*(2400)^-$	19.3 ± 2.8	0.21	1.39	1.43	0.40	2.04
$D_2^*(2460)^-$	23.1 ± 1.2	0.70	0.70	0.49	0.15	1.11
$D\pi$ S-wave (dabba)	6.6 ± 1.4	0.03	0.81	0.59	0.57	1.15
$D\pi$ P-wave (EFF)	8.9 ± 1.6	0.86	1.91	0.52	0.38	2.19
$m\,(D_0^*(2400)^-)$	2360 ± 15	4.6	8.1	7.0	3.7	12.2
$m\,(D_2^*(2460)^-)$	2465.6 ± 1.8	0.01	0.37	0.22	0.29	0.51
$\Gamma\,(D_0^*(2400)^-)$	255 ± 26	2.8	13.1	13.9	4.8	19.9
$\Gamma\,(D_2^*(2460)^-)$	46.0 ± 3.4	0.5	0.9	0.9	0.5	1.4

Resonance	Central value	Fixed parameters	Add/remove	Alternative models	Total
$K^*(892)^0$	37.4 ± 1.5	0.75	1.14	1.09	1.74
$K^*(1410)^0$	0.7 ± 0.3	0.18	0.70	0.22	0.76
$K_0^*(1430)^0$	5.1 ± 2.0	0.79	3.30	0.23	3.40
LASS nonresonant	4.8 ± 3.8	1.10	3.99	5.20	6.65
LASS total	6.7 ± 2.7	0.53	1.42	5.21	5.43
$K_2^*(1430)^0$	7.4 ± 1.7	0.36	1.87	0.56	1.98
$D_0^*(2400)^-$	19.3 ± 2.8	0.55	1.95	7.11	7.40
$D_2^*(2460)^-$	23.1 ± 1.2	0.18	0.73	0.99	1.24
$D\pi$ S-wave (dabba)	6.6 ± 1.4	0.27	1.40	3.46	3.74
$D\pi$ P-wave (EFF)	8.9 ± 1.6	0.31	1.99	2.15	2.95
$m\,(D_0^*(2400)^-)$	2360 ± 15	6.1	9.3	25.6	27.9
$m\,(D_2^*(2460)^-)$	2465.6 ± 1.8	0.09	1.05	0.48	1.15
$\Gamma\,(D_0^*(2400)^-)$	255 ± 26	4.0	18.0	43.5	47.2
$\Gamma\,(D_2^*(2460)^-)$	46.0 ± 3.4	1.4	0.5	2.4	2.9

γ from $B^0 \to DK^+\pi^-$

PR D93 (2016) 112018



$D \to KK, \pi\pi$

γ from $B^0 \to DK^+\pi^-$

Experimental systematic ...

PR D93 (2016) 112018

Parameter	Uncertainty							
	$\mathcal{S}/\mathcal{B}$	ϵ	$\mathcal{B}$ DP	fit bias	$\mathcal{B}$ asym.	$\mathcal{B}$ DP asym.	ϵ asym.	total
x_+	0.010	0.035	0.046	0.021	0.007	0.049	0.000	0.079
x_-	0.026	0.028	0.063	0.019	0.010	0.045	0.001	0.089
y_+	0.019	0.042	0.122	0.066	0.017	0.027	0.000	0.149
y_-	0.024	0.022	0.054	0.035	0.018	0.071	0.000	0.103

… and model uncertainties

Parameter	Uncertainty					
	fixed pars.	add/rem.	alt. mod.	D_s^{**} CPV	$K\pi_{\text{S-wave}}$ CPV	total
x_+	0.027	0.028	0.068	0.008	0.003	0.079
x_-	0.030	0.034	0.076	0.056	0.022	0.107
y_+	0.075	0.061	0.131	0.012	0.047	0.170
y_-	0.040	0.066	0.255	0.286	0.064	0.396