Non-leptonic three body decays at LHCb

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On behalf of the LHCb experiment

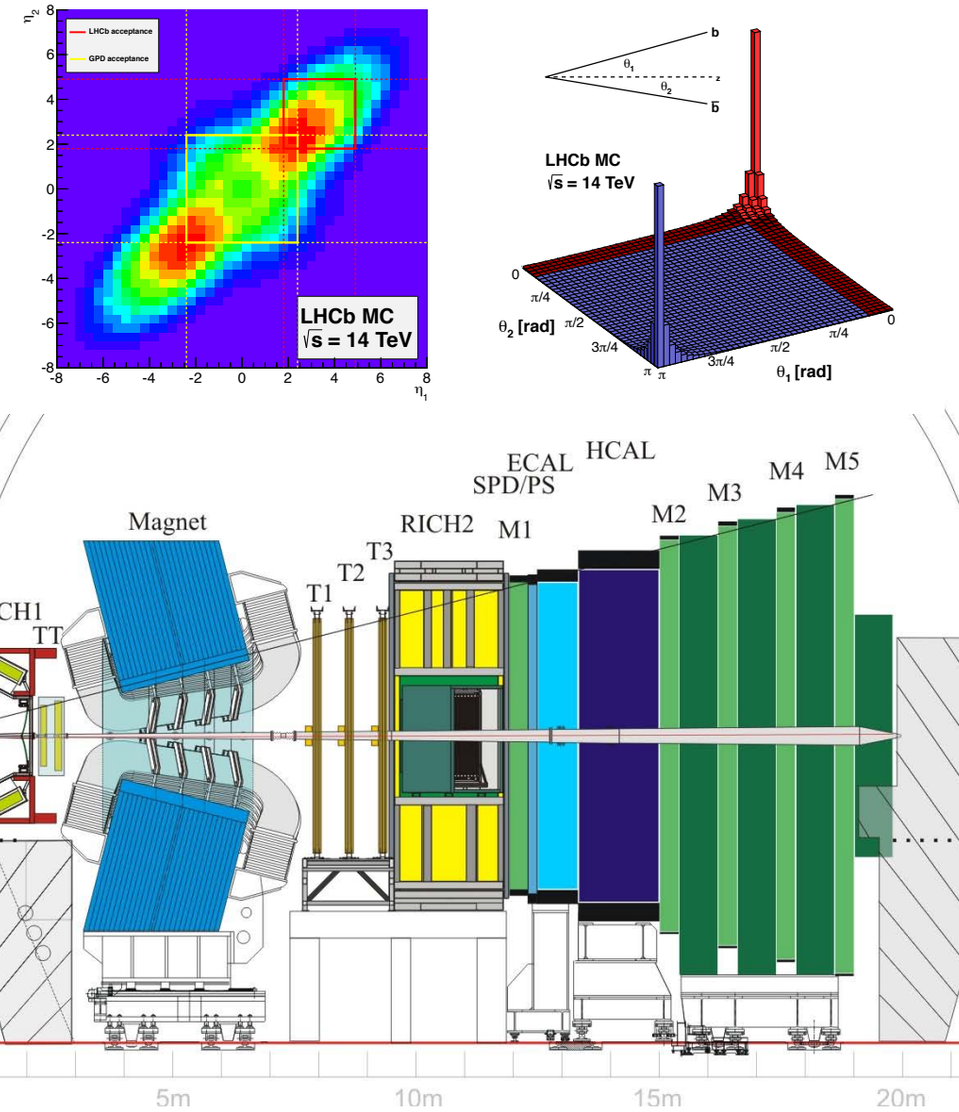
February 14th, 2018

Pion-Kaon Interaction Workshop

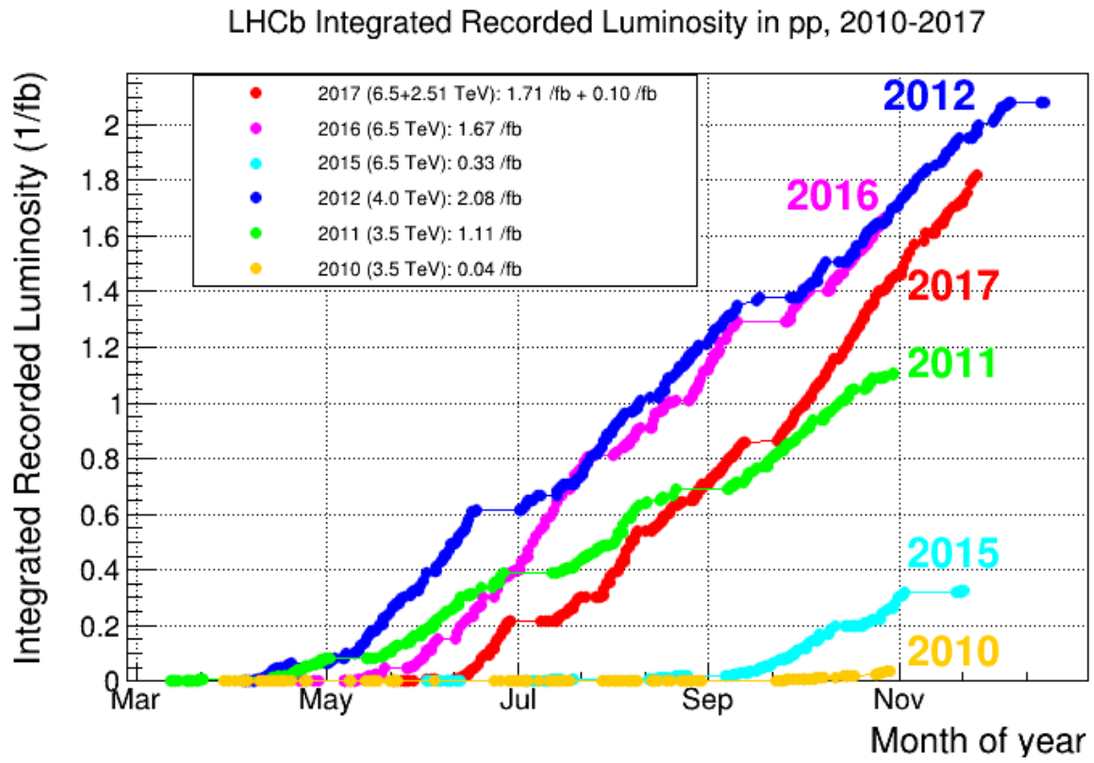
LHCb detector status

Universität Zürich[UZH]

Spectrometer mainly dedicated to heavy flavour physics



[Int. J. Mod. Phys. A 30 (2015) 1530022]



[$3\,\mathrm{fb}^{-1}$ Run-I (2011/12) at 7/8 TeV]

[$3.7\,\mathrm{fb}^{-1}$ Run-II (2015-17) at 13 TeV]

Outline

This talk covers some recent highlights in this sector from LHCb

[$3\,\text{fb}^{-1}$ Run-I (2011/12) at 7/8 TeV]

- Introduction to three-body decays at LHCb

- B decays to open charm, *i.e.* B → Dhh' modes

  Dalitz plot analyses, (strange-)charm spectroscopy

  [PRL 113, 162001 (2014), PRD 90, 072003 (2014)]
  [PRD 92, 012012 (2015)]

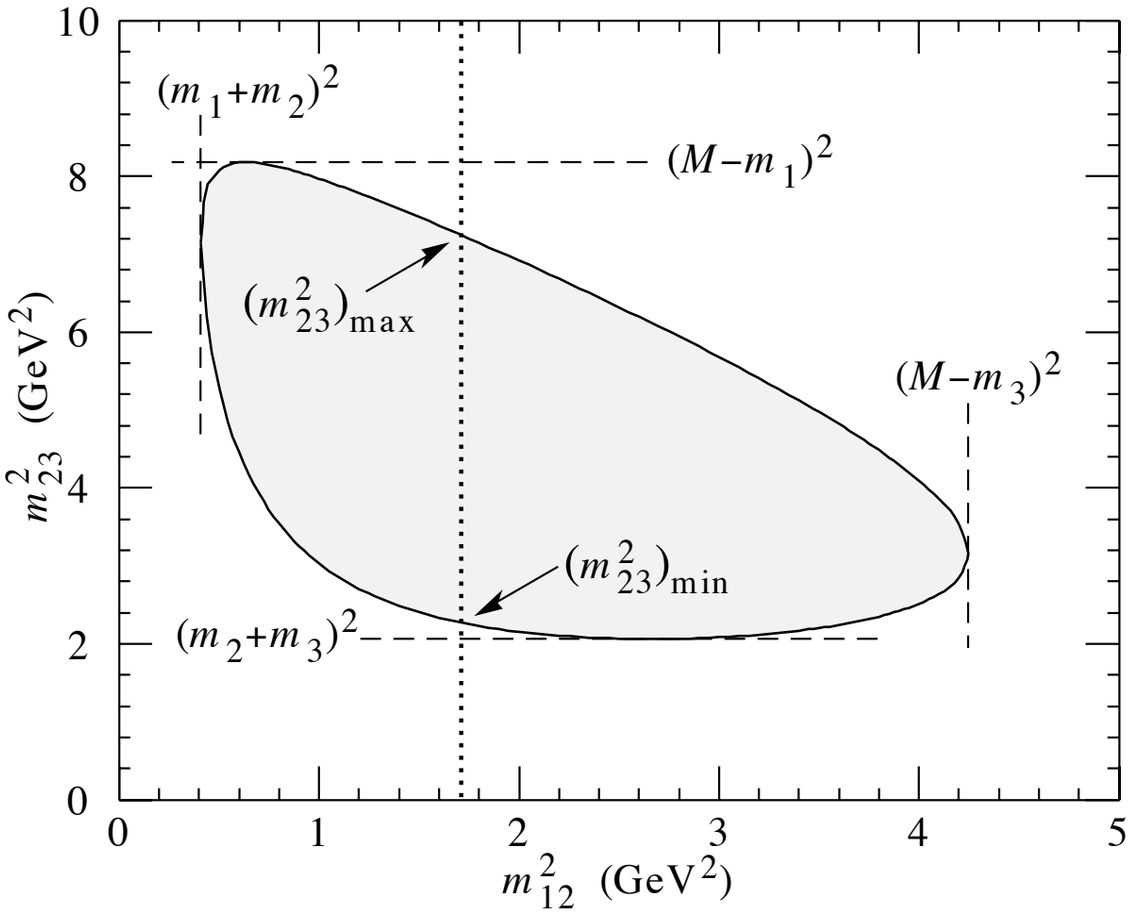
- CPV measurements in charmless three-body decays involving K^0_S

  [JHEP 10 (2013) 143, JHEP 11 (2017) 027]
  [LHCb-PAPER-2017-033, submitted to PRL]

- Status/issues towards more DP analyses

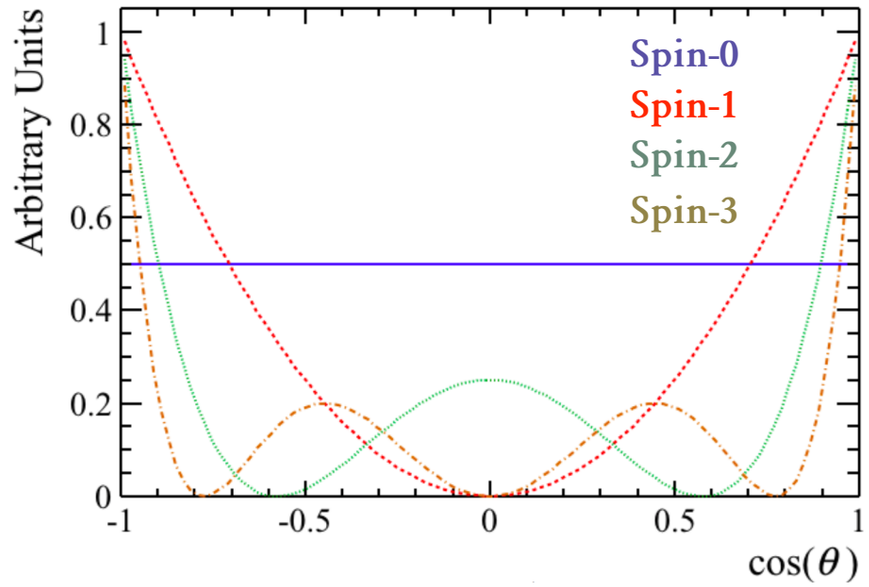
Dalitz plot analysis features

Intensity along bands indicates magnitude and the spin of the given resonance



Particle Data Group Collaboration
PRD 86 (2012) 010001

Angular distribution of resonance related to Legendre Polynomials

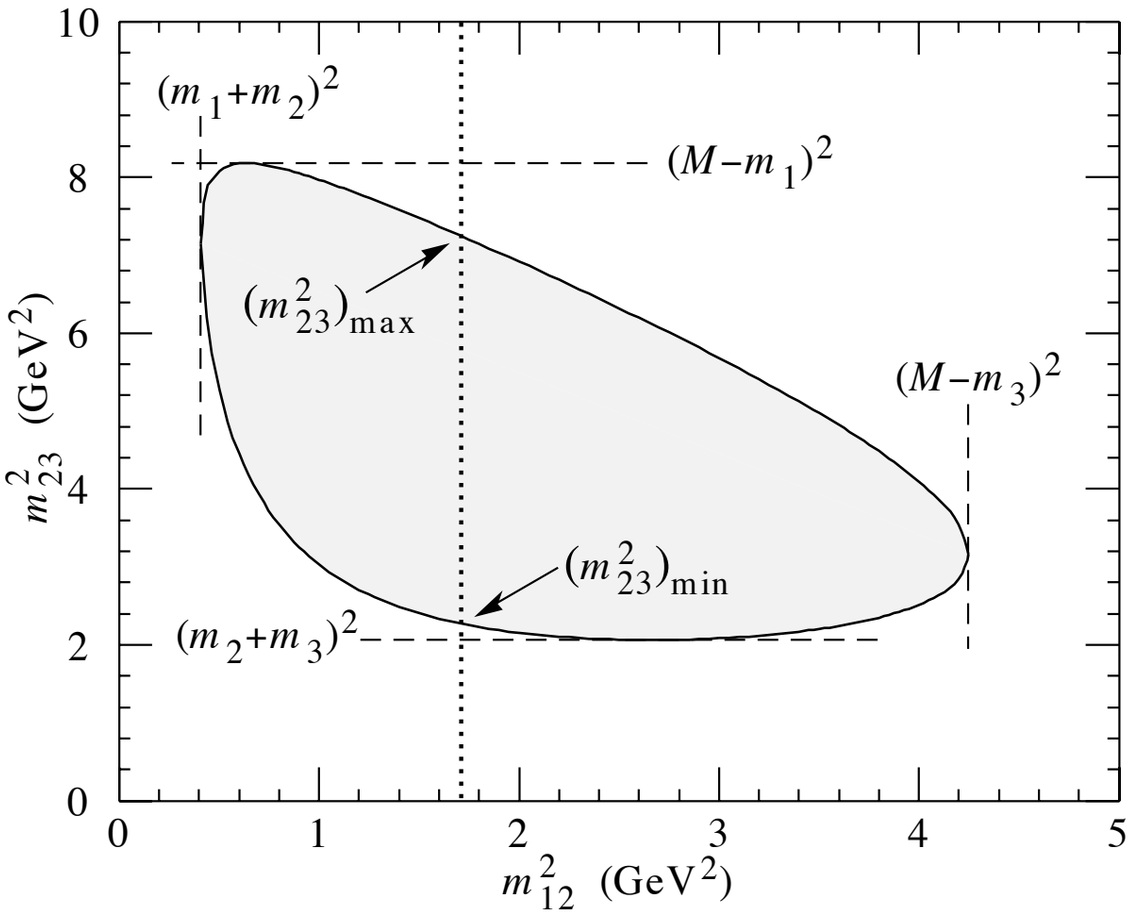


Amplitude analysis can access:

- Relative phases between states
- Sensitivity to CP violating effects
- Resolve ambiguities in weak phases
- Hadron spectroscopy

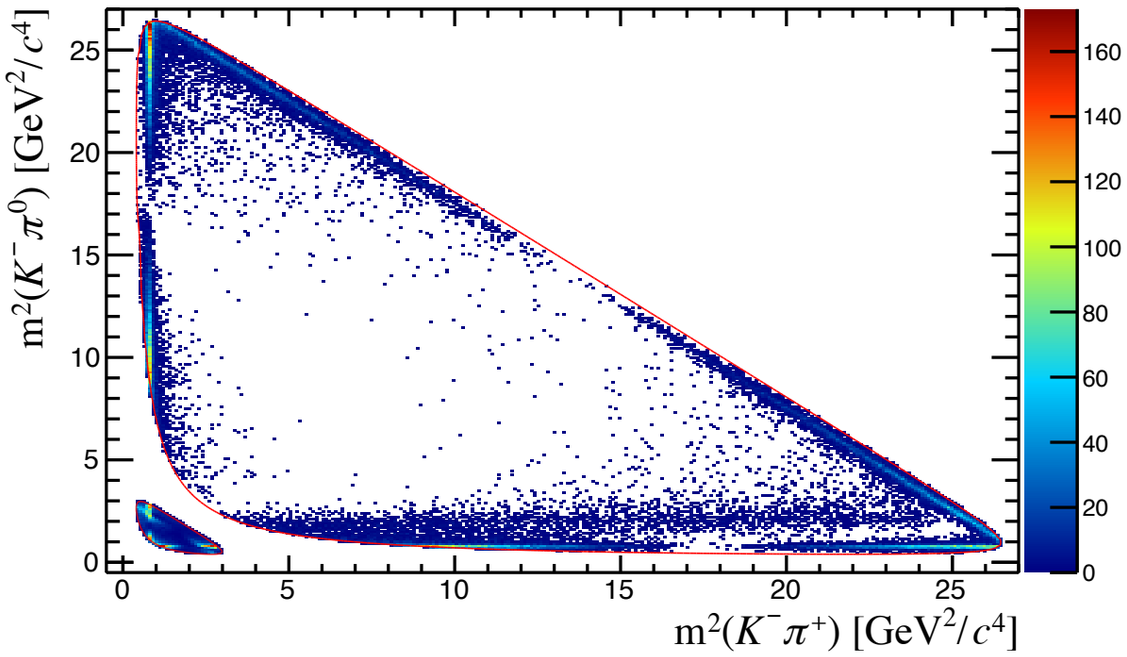
Dalitz plot analysis features

Intensity along bands indicates magnitude and the spin of the given resonance



Particle Data Group Collaboration
PRD 86 (2012) 010001

Toy simulation using Laura++ package:
arXiv:1711.09854, https://laura.hepforge.org



Amplitude analysis can access:

- Relative phases between states
- Sensitivity to CP violating effects
- Resolve ambiguities in weak phases
- Hadron spectroscopy

Dalitz plot analysis - Isobar Model

Amplitude analysis most commonly performed in the "Isobar Model", in which the total amplitude is approximated as coherent sum of quasi-two-body contributions:

CP violating Strong dynamics *CP* conserving

$$\mathcal{A}(m_{ij}^2, m_{jk}^2) = \sum_{l=1}^{N} c_l F_l(m_{ij}^2, m_{jk}^2)$$

c_l : complex coefficients describing the relative magnitude and phase of the different isobars

F_l: dynamical amplitudes that contain the lineshape and spin-dependence of the hadronic part

$$F_l(L, m_{ij}^2, m_{jk}^2) = R_l(m_{ij}^2) \times X_L(|\vec{p}|r) \times X_L(|\vec{q}|r) \times T_l(L, \vec{p}, \vec{q})$$

Resonance mass term (e.g. Breit–Wigner)

Barrier factors - *p*, *q*: momenta of bachelor and resonance

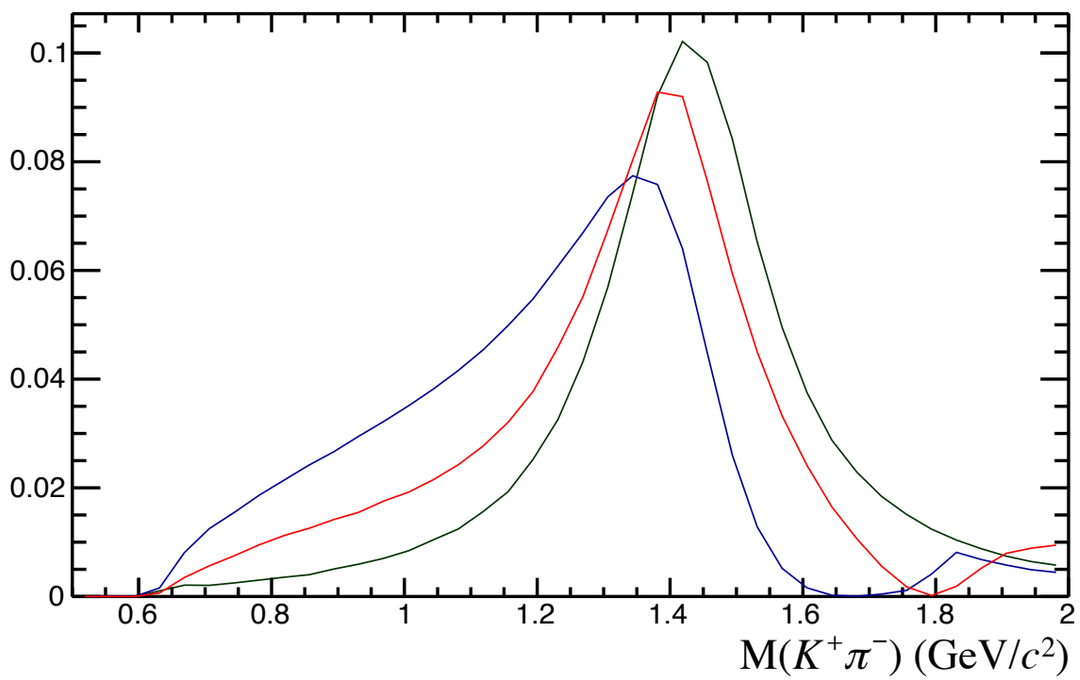
Angular probability distribution

Many observables can be accessed: $\mathrm{Re}(c_i)$ and $\mathrm{Im}(c_i)$ or $|c_i|$ and $\arg(c_i)$; or derived quantities such as BF and A_{CP}

Kπ invariant mass modelling

- **K*(892)** resonance - Relativistic Breit-Wigner
- **Kπ S-wave** contribution

Toy simulation using Laura++ package
arXiv:1711.09854



— LASS lineshape [Nucl. Phys. B296 (1988) 493]

$$R_j(s) = \frac{\sqrt{s}}{q\cot\delta_B - iq} + e^{2i\delta_B}\frac{m_0\Gamma_0\frac{m_0}{q_0}}{(m_0^2 - s) - im_0\Gamma_0\frac{q}{\sqrt{s}}\frac{m_0}{q_0}}$$

— EFKLLM lineshape [PRD 79 (2009) 094005]

$$R_j(m) = F(m)\left(\frac{c_0}{m^2} + c_1\right)$$

— κ + $K^*_0(1430)$ resonance [Flatté]

NR parametrisation [PRD 92 (2015) 054010]

$$R_j(s) = \frac{1}{1 + \frac{s}{\Lambda^2}}$$

Single model κ + $K^*_0(1430)$ + $K^*_0(1950)$
[arXiv:1701.04881]

Others (non DP), polynomial expansion
[PRD 93 (2016) 074025]

Universität Zürich[UZH]

B decays to open charm, *i.e.* B → Dhh' channels

Dalitz-plot analyses (*e.g.* spectroscopy and CKM angle measurements)

(strange-)charm spectroscopy

[PRL 113, 162001 (2014), PRD 90, 072003 (2014)]
[PRD 92, 012012 (2015)]

LHCb

$D_s^{(**)}$ spectroscopy - $B^0_s \to \bar{D}^0 K^- \pi^+$

Universität Zürich[UZH]

Spectroscopy of strange-charm states has been reinvigorated due to recent observations of $D_{s0}^*(2317)$ and $D_{s1}(2460)$

PRD 89, 074023 (2014)
Stephen Godfrey, Ian T. Jardine

DP analysis of $B^0_s \to D_s^{**}(\bar{D}^0 K^-)\pi^+$

$D_{sJ}^*(3040)^-$

$D_{sJ}^*(2860)^-$

$D_{s1}^*(2700)^-$

$D_{s2}^*(2573)^-$

$D_{s1}(2536)^-$

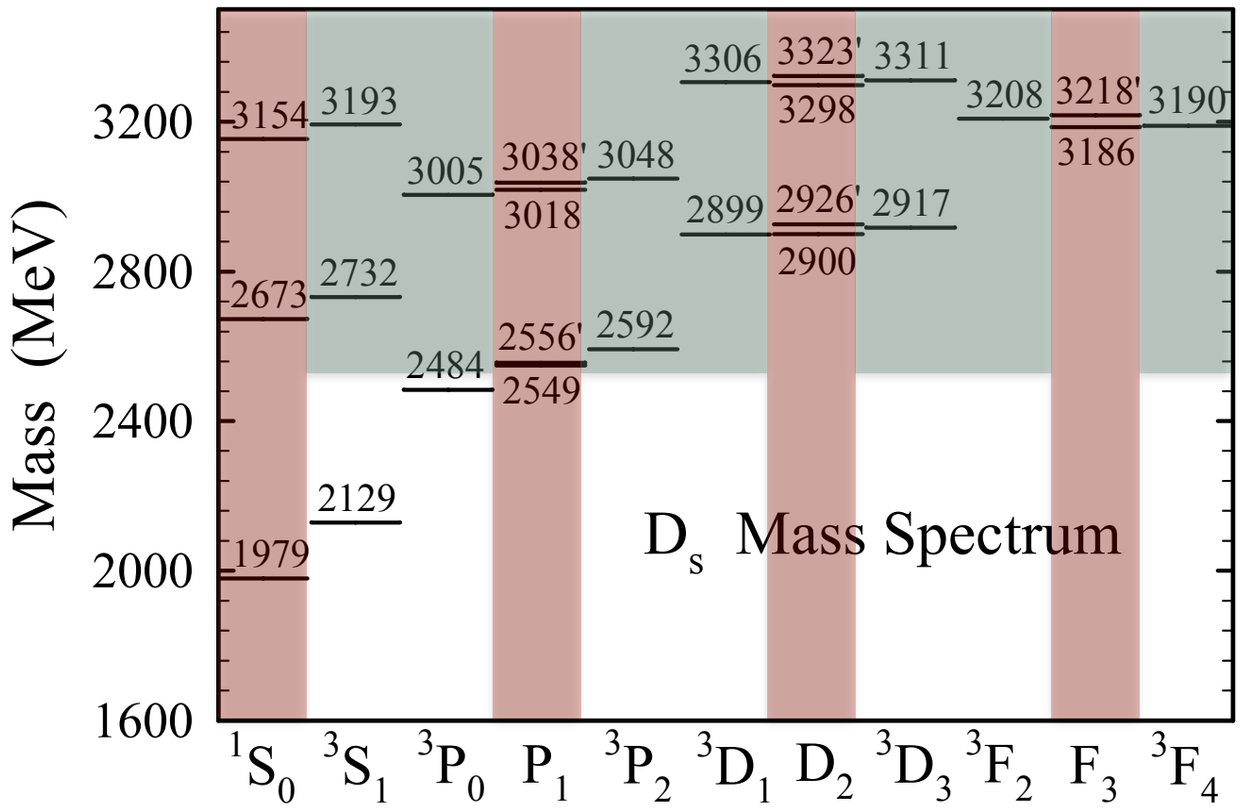
$D_{s1}(2460)^-$

$D_{s0}^*(2317)^-$

Some discrepancies have been seen between predicted and measured values

D_s^{*-}

D_s



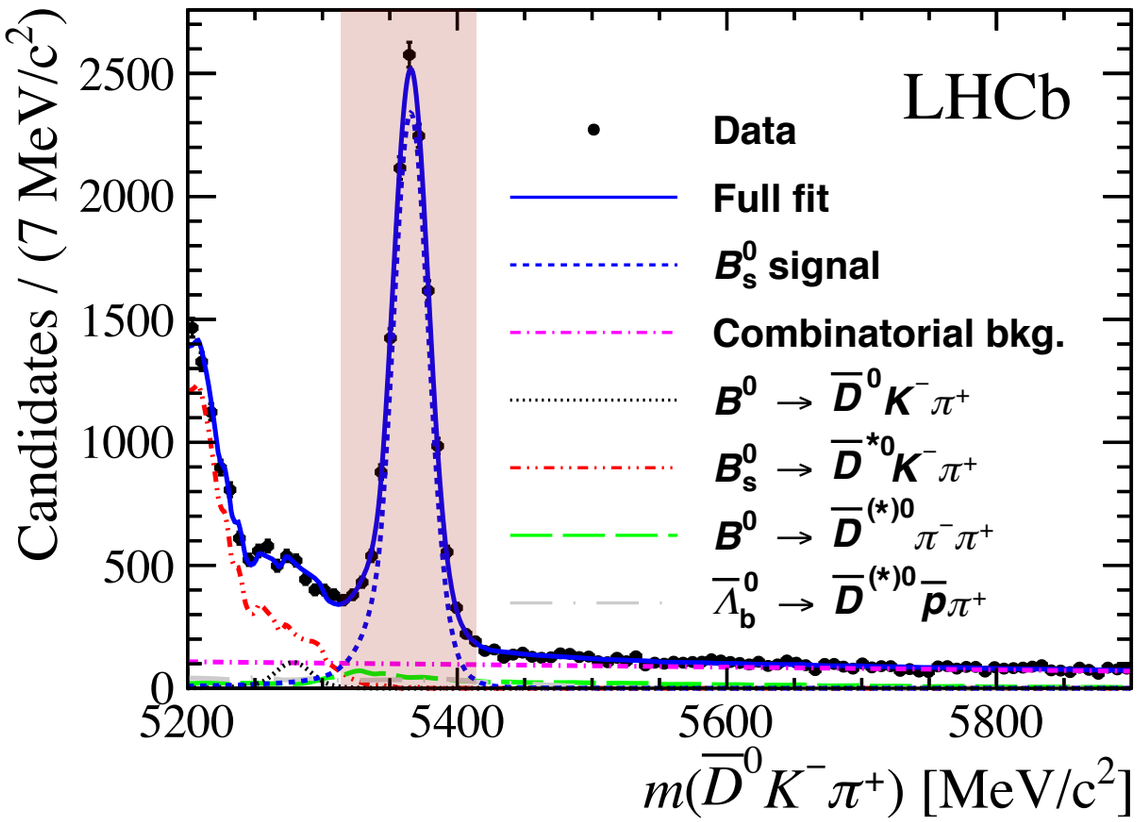
- D_s^* and $D_{s0}^*(2317)$ are too light to decay to D^0K^-
- Neither can states with unnatural spin-parity ($J^P = 0^-, 1^+, 2^-$, etc)
- $D_{s2}^*(2573)$, $D_{s1}^*(2700)$ and $D_{sJ}^*(2860)$ are possible

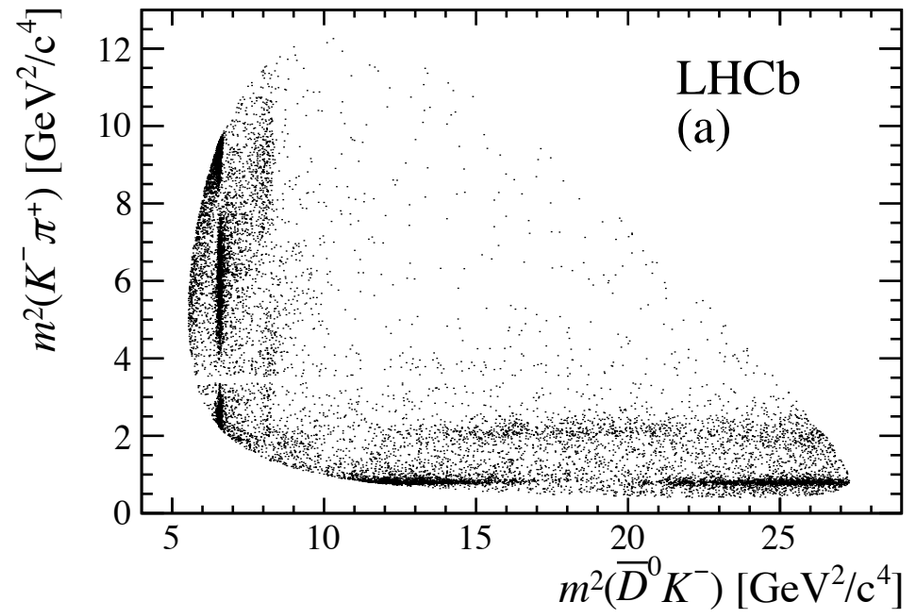
Dalitz plot analysis of $B^0_s \to \bar{D}^0 K^- \pi^+$

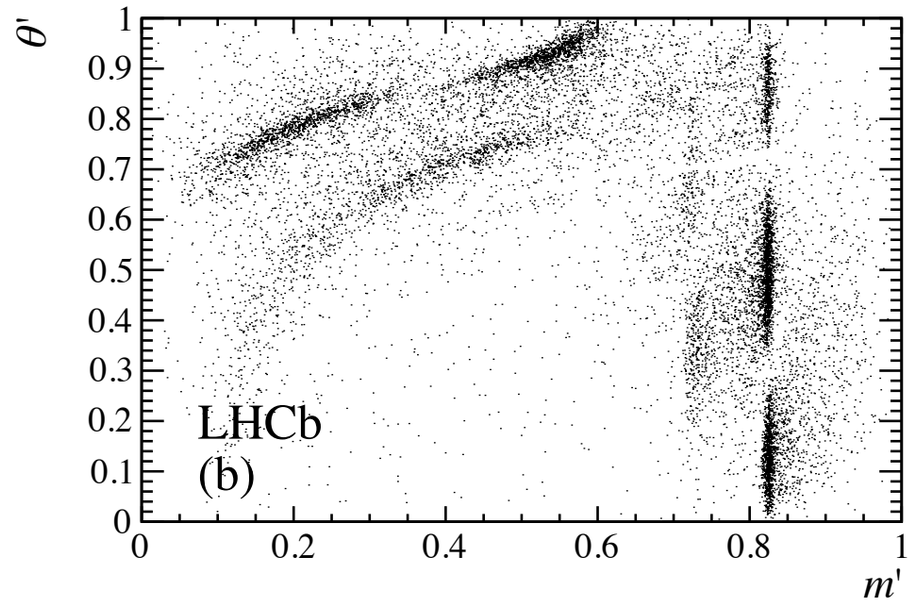
Analysis performed with ~11K signal events and purity of 87%

Backgrounds due to Combinatorial (7.3%), $B^0 \to D^{(*)0}\pi\pi$ (2.8%) and $\Lambda^0_b \to D^{(*)0}p\pi$ (2.3%)

LHCb PRL 113, 162001 (2014), PRD 90, 072003 (2014)





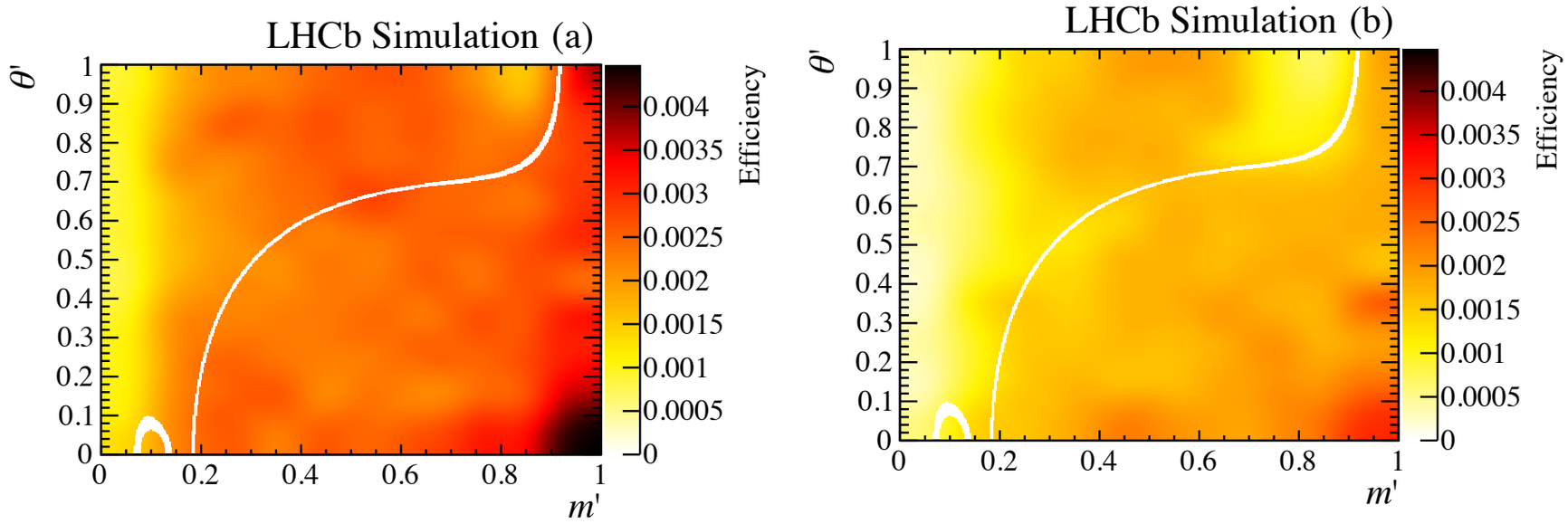


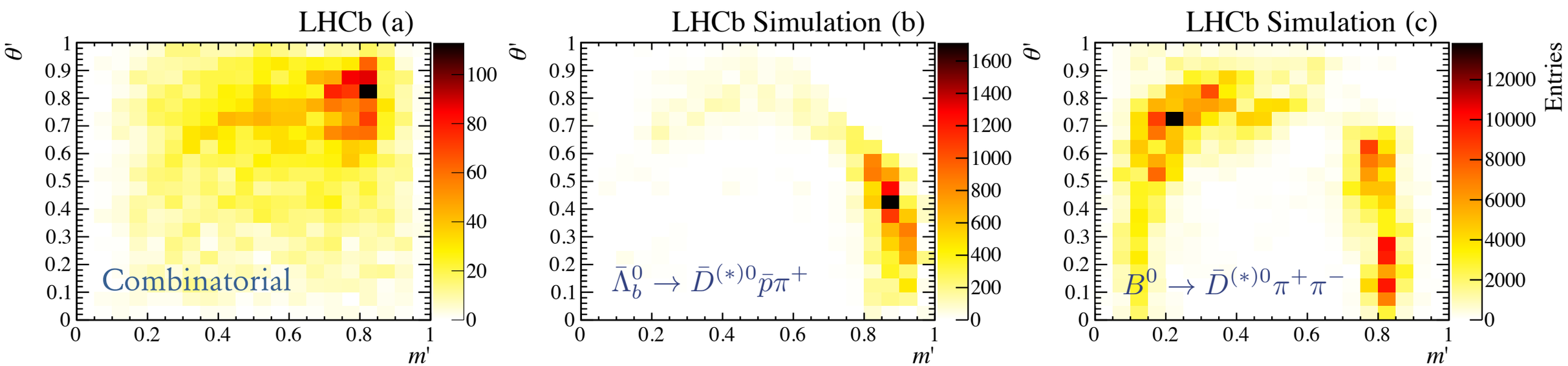
$$m' \equiv \frac{1}{\pi}\arccos\left(2\frac{m_{ij}-m_{ij}^{\min}}{m_{ij}^{\max}-m_{ij}^{\min}}-1\right) \qquad \theta' = \frac{1}{\pi}\theta_{ij}$$

Dalitz plot analysis overview

LHCb PRL 113, 162001 (2014), PRD 90, 072003 (2014)

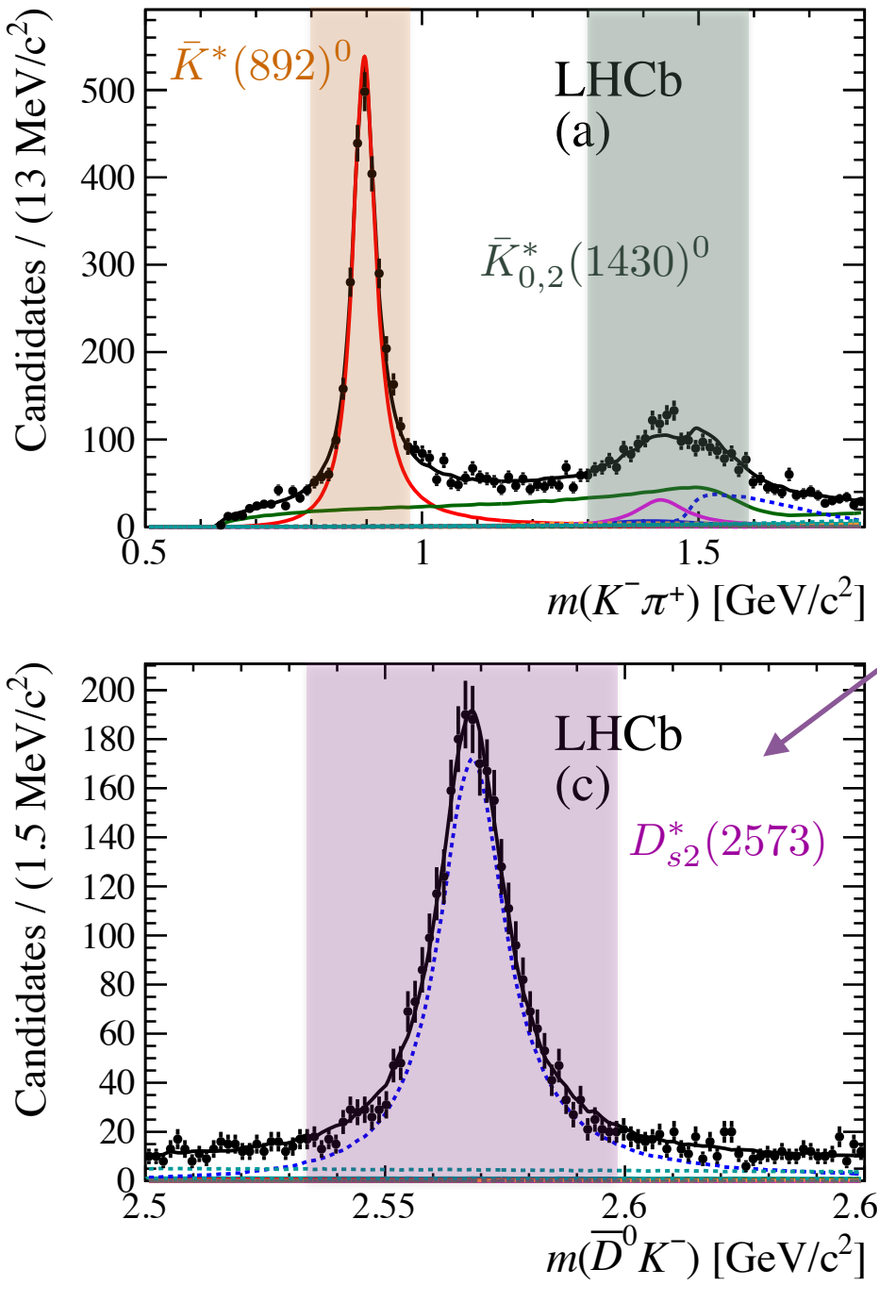
Efficiency (Spline) and background contributions need to be modelled for the Dalitz-plot fit

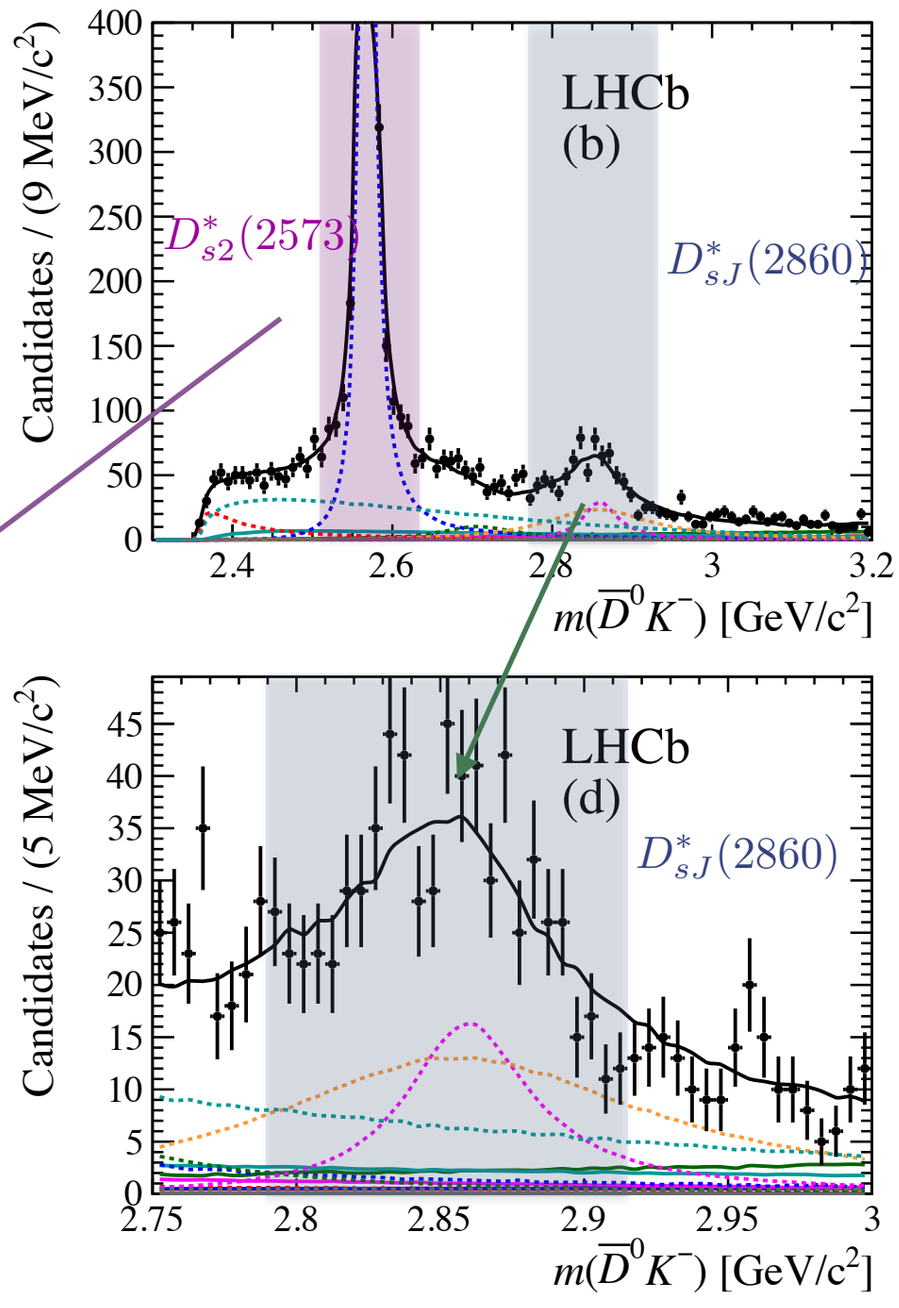




Dalitz plot fit results

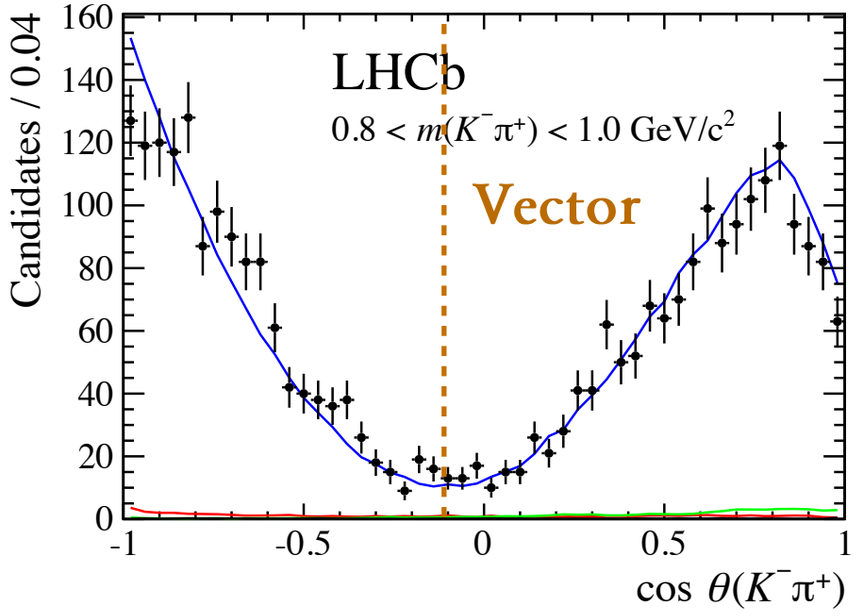
LHCb PRL 113, 162001 (2014), PRD 90, 072003 (2014)

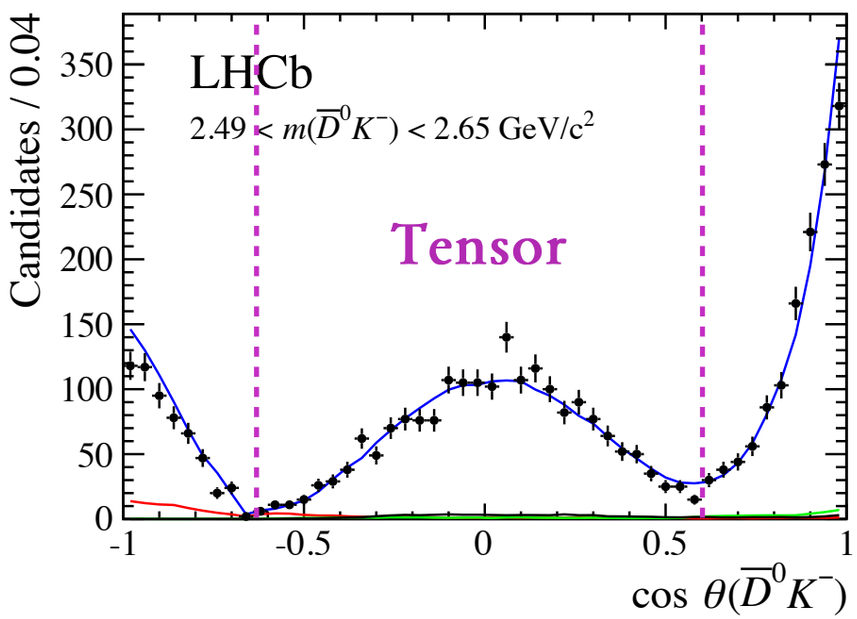


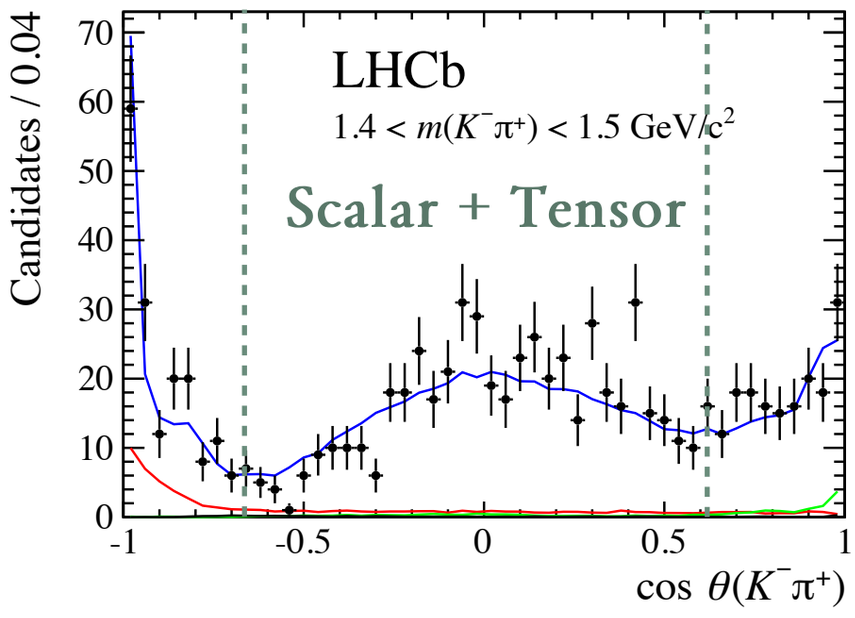


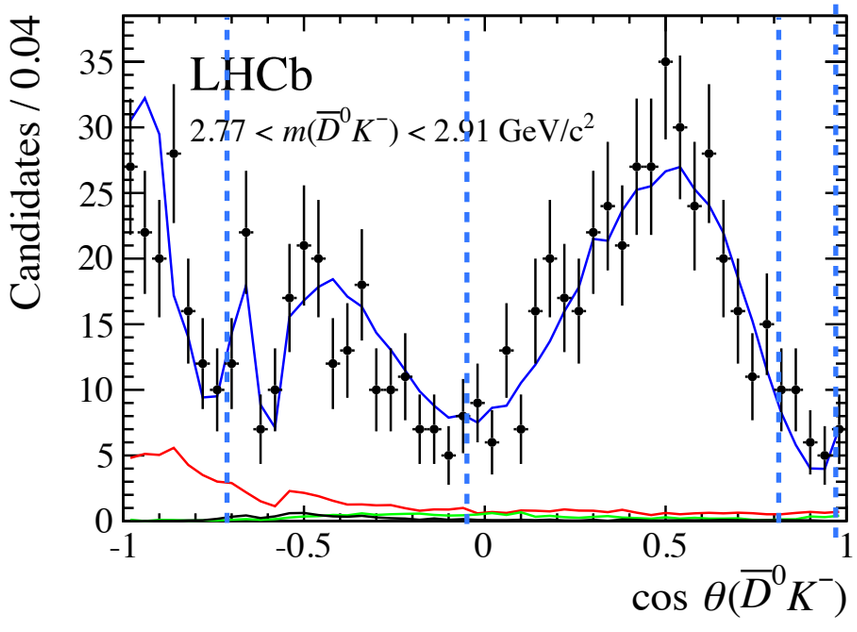
Dalitz plot fit results - helicity projections

LHCb PRL 113, 162001 (2014), PRD 90, 072003 (2014)









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$D_{sJ}^{*}(2860)^{-}$ state

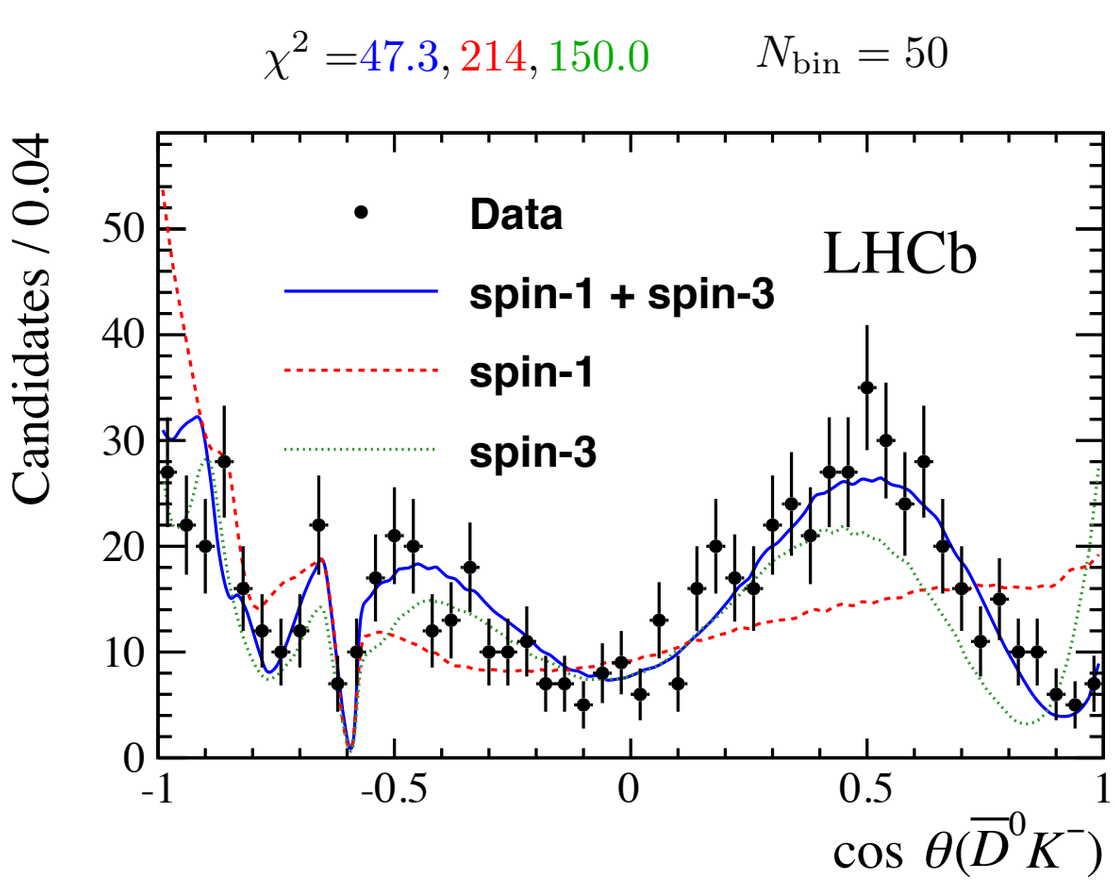
Several spin hypotheses have been investigated for the $D_{sJ}^{*}(2860)^{-}$

Two states [$\mathbf{D_{s1}^{*}(2860)^{-}}$, $\mathbf{D_{s3}^{*}(2860)^{-}}$] are required in the region 2.86 GeV/c^2 (each with a significance of 10σ)

1st observation of a heavy flavoured spin-3 resonance and 1st time a spin-3 state seen to be produced in B decay

Spin hypothesis	ΔNLL	$\sqrt{2\Delta NLL}$	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		

LHCb PRL 113, 162001 (2014), PRD 90, 072003 (2014)

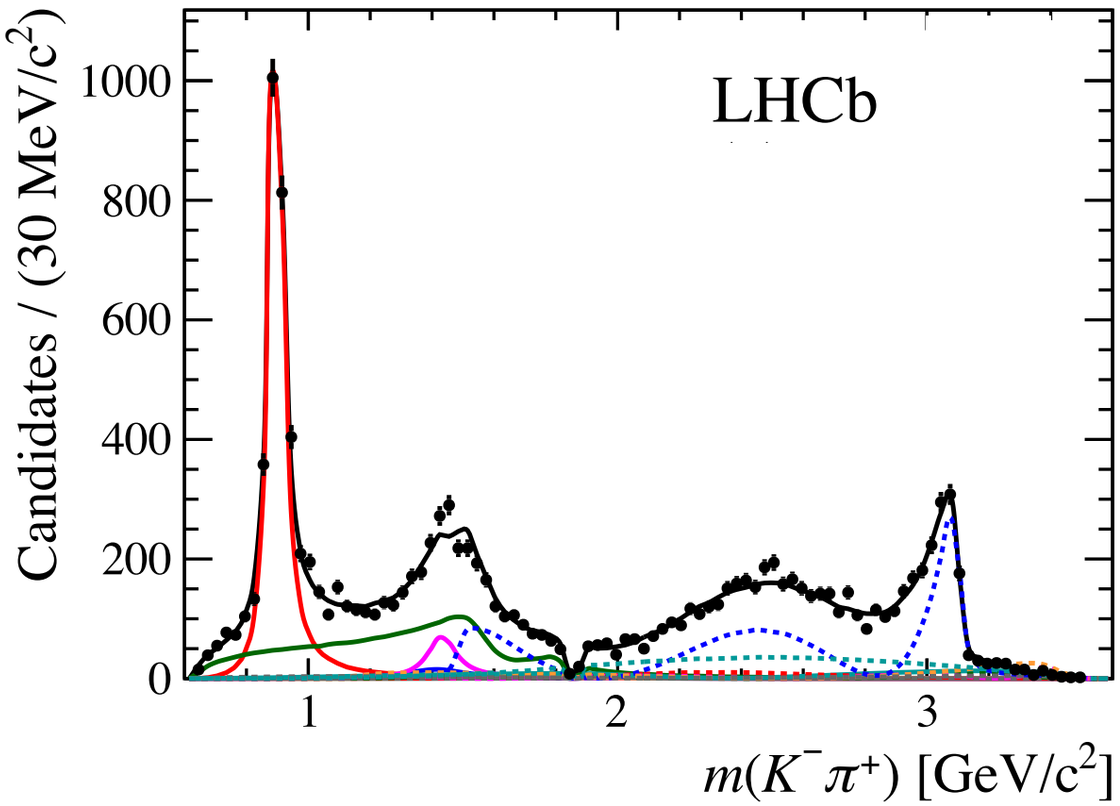


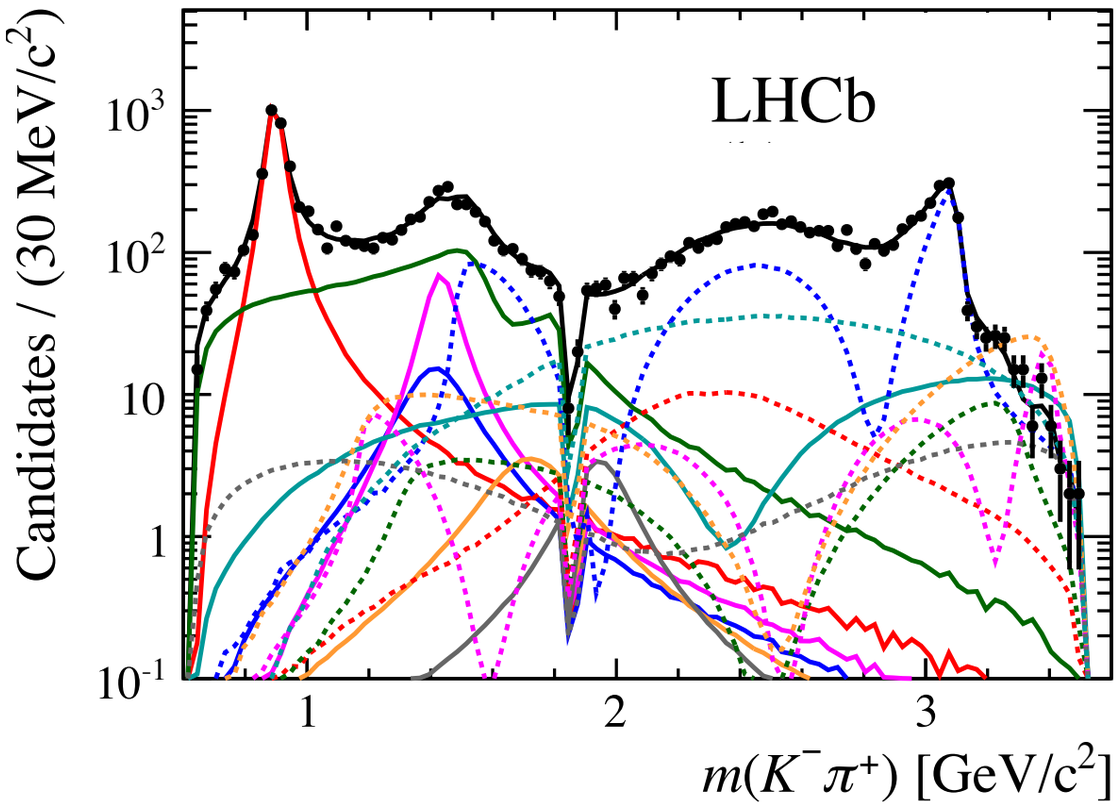
The presence of the state $D_{s3}^{*}(2860)$ has been independently confirmed in studies of $pp \rightarrow D^{*(+,0)}K^{0,+}X$ (LHCb)

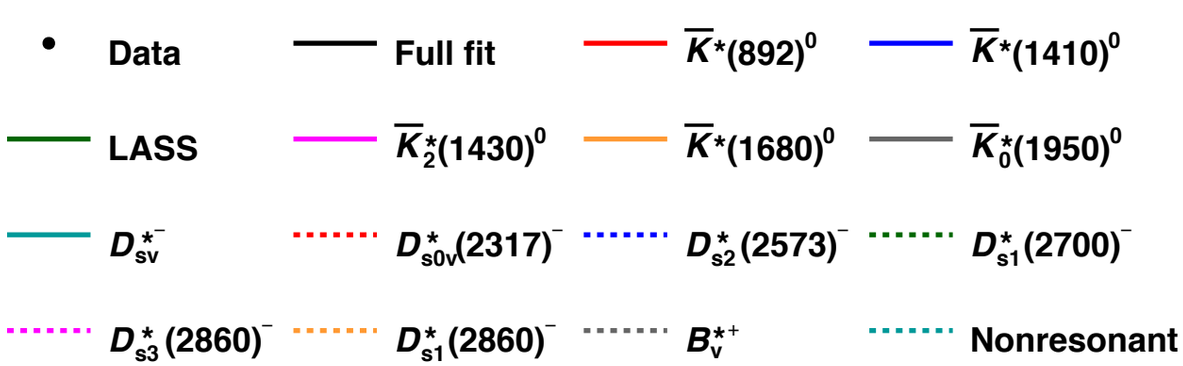
LHCb JHEP 02 (2016) 133

Dalitz plot fit results

LHCb PRL 113, 162001 (2014), PRD 90, 072003 (2014)

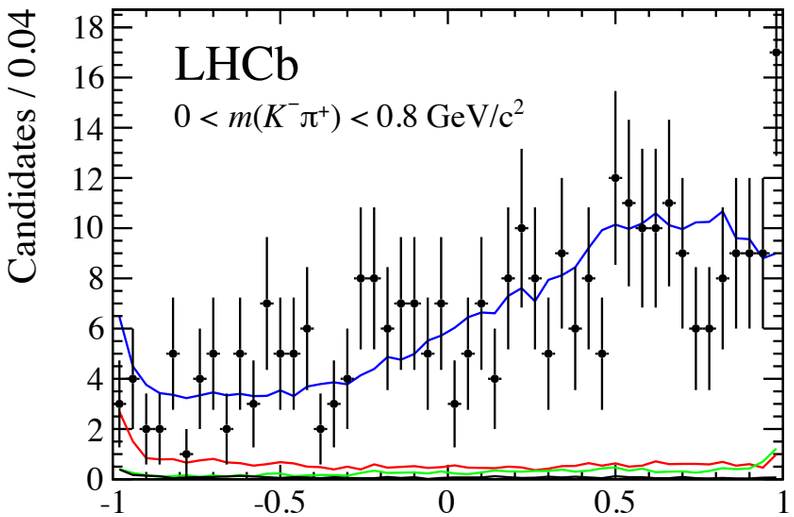


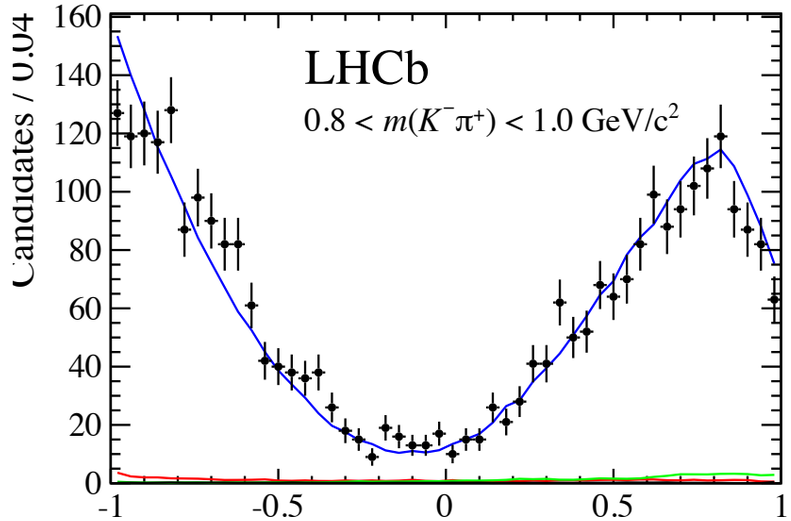


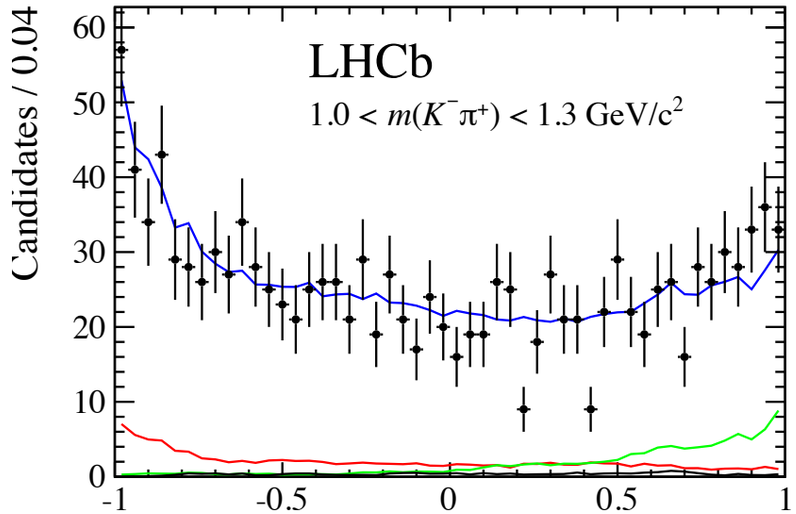


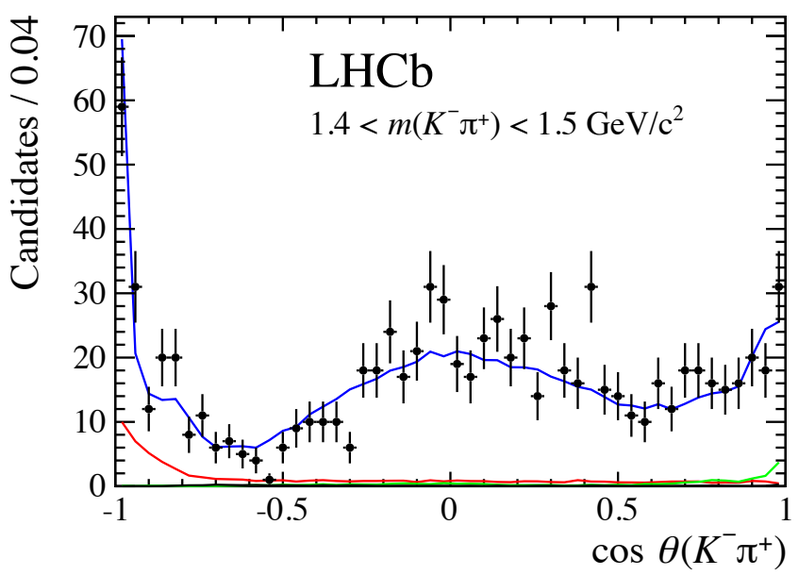
Dalitz plot fit results

LHCb PRL 113, 162001 (2014), PRD 90, 072003 (2014)









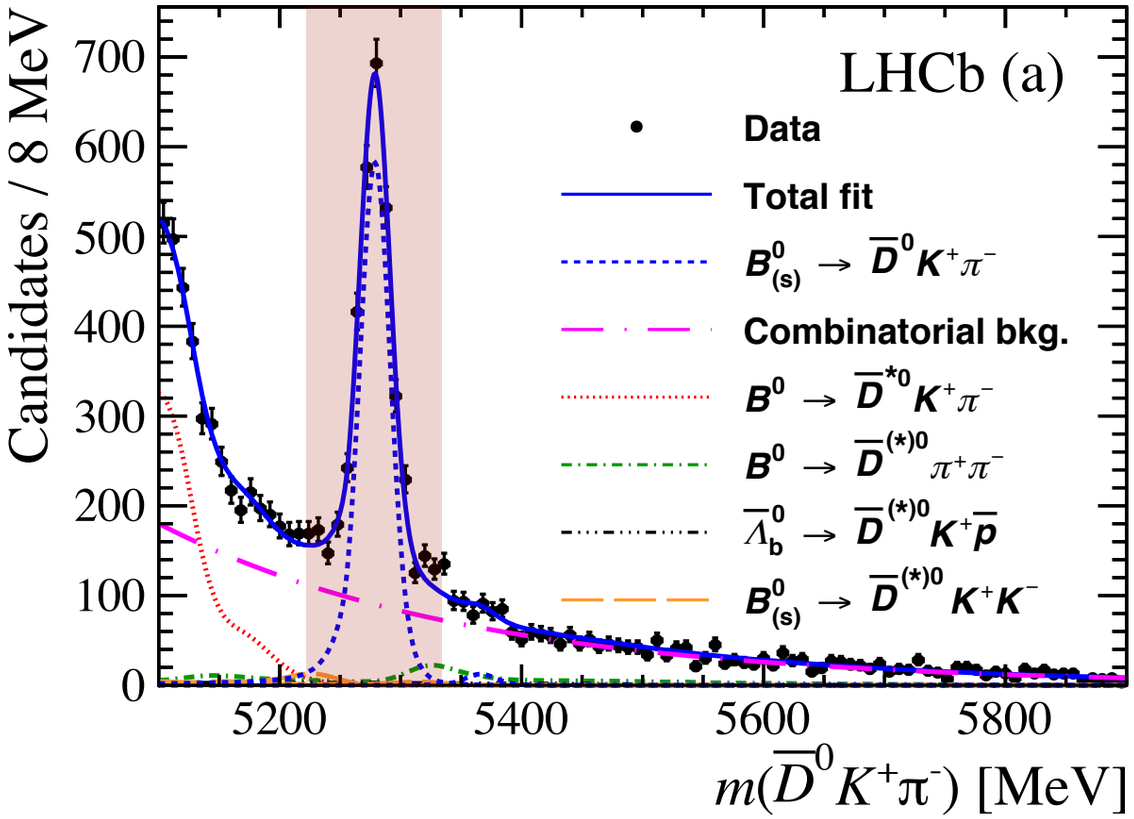
Resonance	Fit fraction	Upper limits 90 % CL	Upper limits 95 % CL
$\overline{K}^*(892)^0$	$28.6 \pm 0.6 \pm 0.7 \pm 0.9$		
$\overline{K}^*(1410)^0$	$1.7 \pm 0.5 \pm 0.2 \pm 1.4$		
LASS nonresonant	$13.7 \pm 2.5 \pm 1.5 \pm 4.1$		
$\overline{K}_0^*(1430)^0$	$20.0 \pm 1.6 \pm 0.7 \pm 3.3$		
LASS total	$21.4 \pm 1.4 \pm 1.0 \pm 4.7$		
$\overline{K}_2^*(1430)^0$	$3.7 \pm 0.6 \pm 0.4 \pm 1.1$		
$\overline{K}^*(1680)^0$	$0.5 \pm 0.4 \pm 0.3 \pm 0.8$	< 2.0	< 2.4
$\overline{K}_0^*(1950)^0$	$0.3 \pm 0.2 \pm 0.1 \pm 2.4$	< 3.7	< 4.1
$\overline{K}_3^*(1780)^0$	—	< 0.33	< 0.38
$\overline{K}_4^*(2045)^0$	—	< 0.21	< 0.24

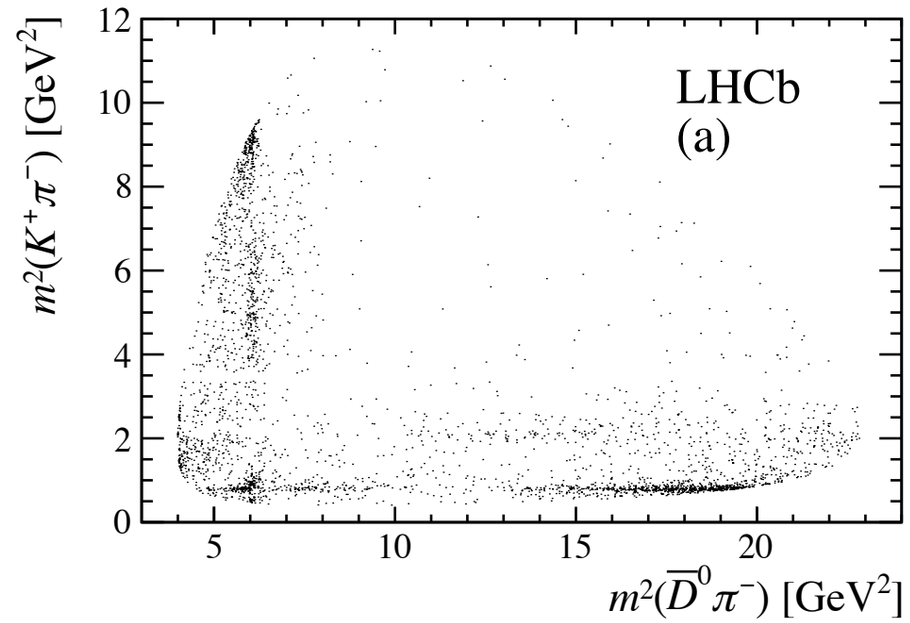
Dalitz plot analysis of $B^0 \to \bar{D}^0 K^+ \pi^-$

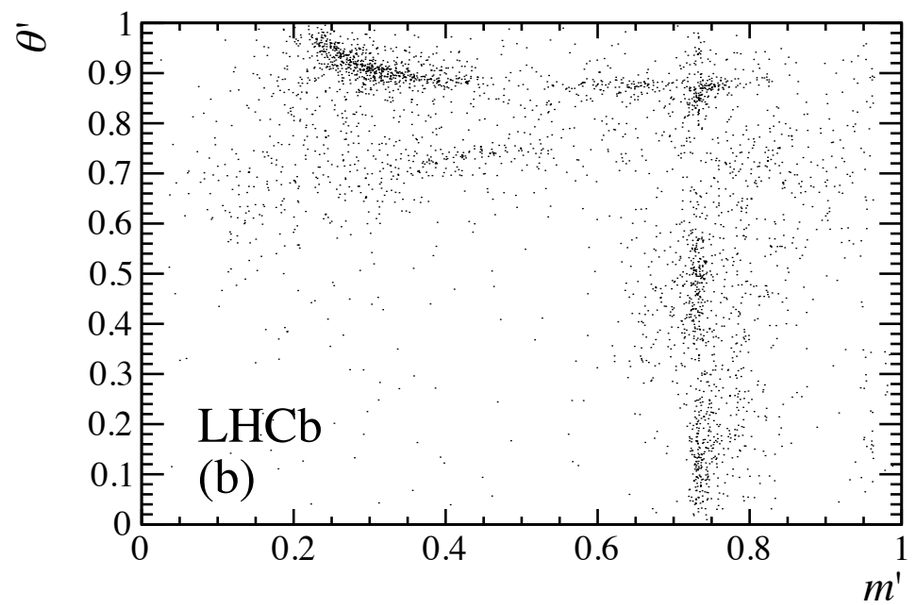
Analysis performed with ~2.3K signal events and purity of 75%

Backgrounds due to Combinatorial (22%), $B^0 \to D^{(*)0}\pi\pi$ (2%) and $\Lambda^0_b \to D^{(*)0}p\pi$ (< 1%)

LHCb PRD 92, 012012 (2015)







Dalitz fit results for $B^0 \to \bar{D}^0 K^+ \pi^-$

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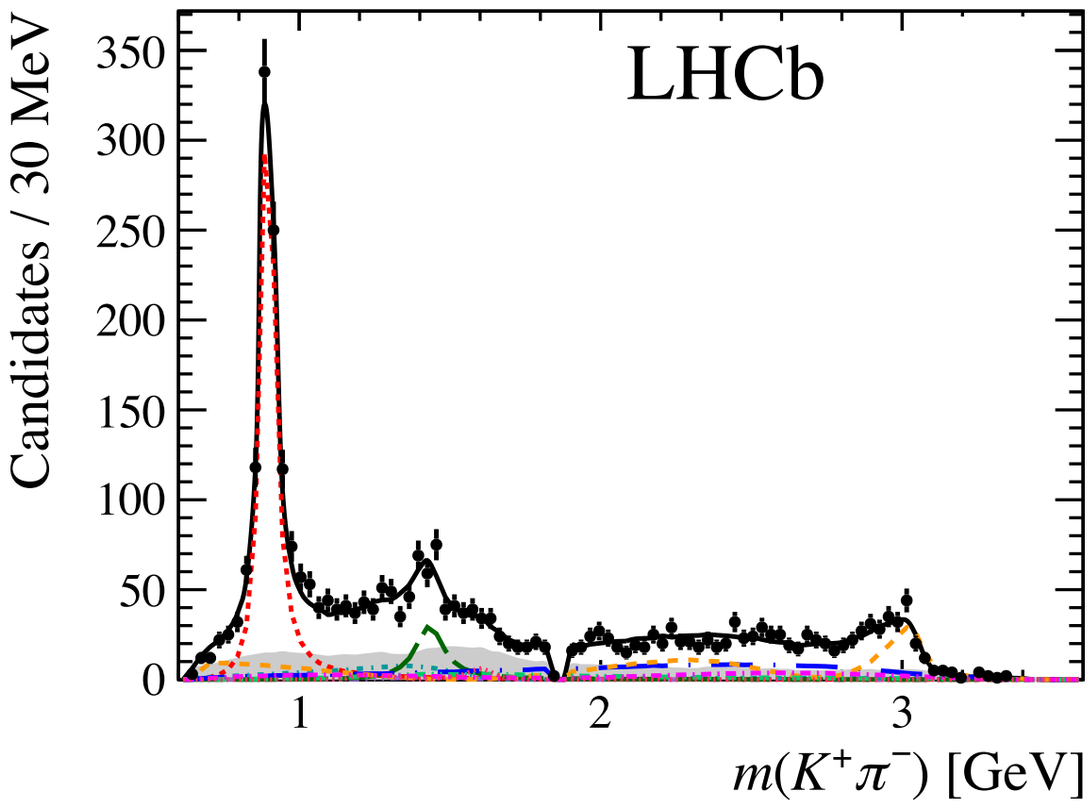
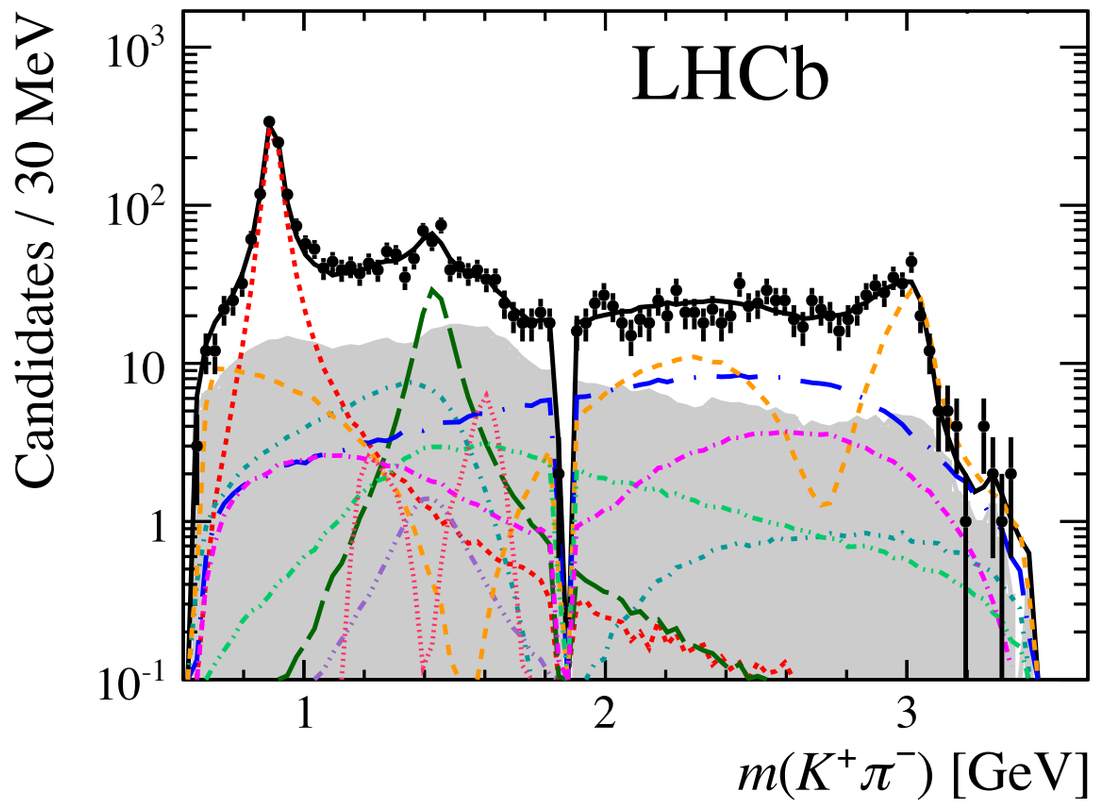
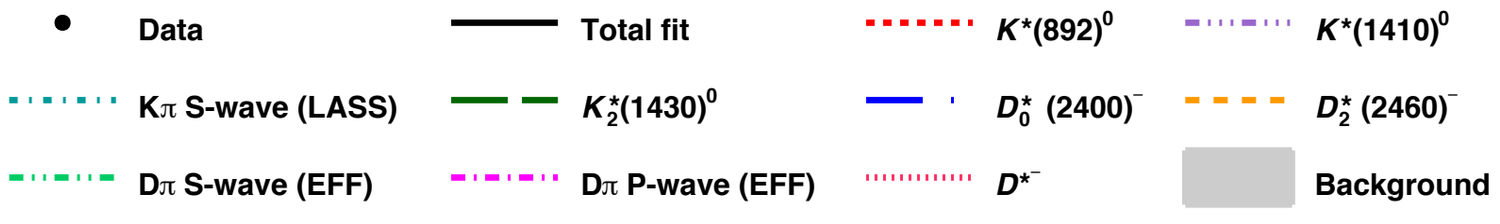
LHCb PRD 92, 012012 (2015)







Dalitz fit results for $B^0 \to \bar{D}^0 K^+ \pi^-$

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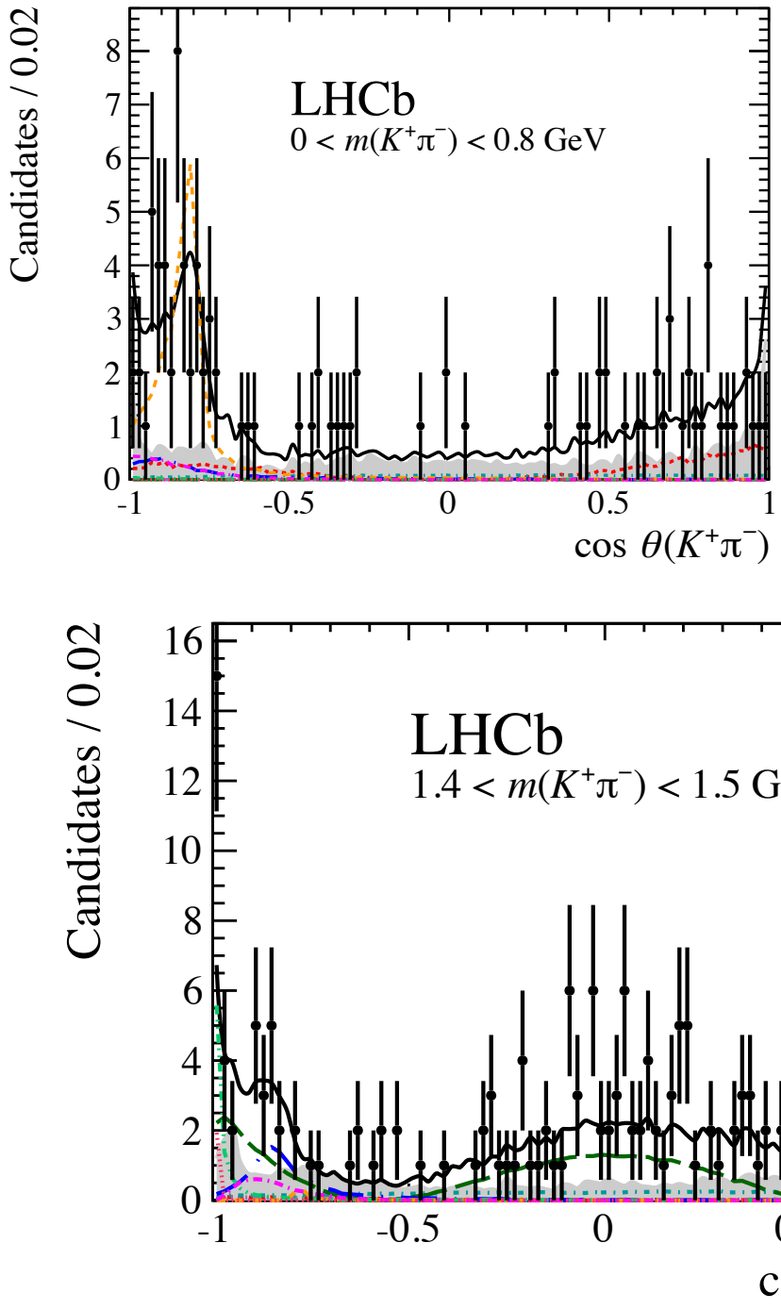
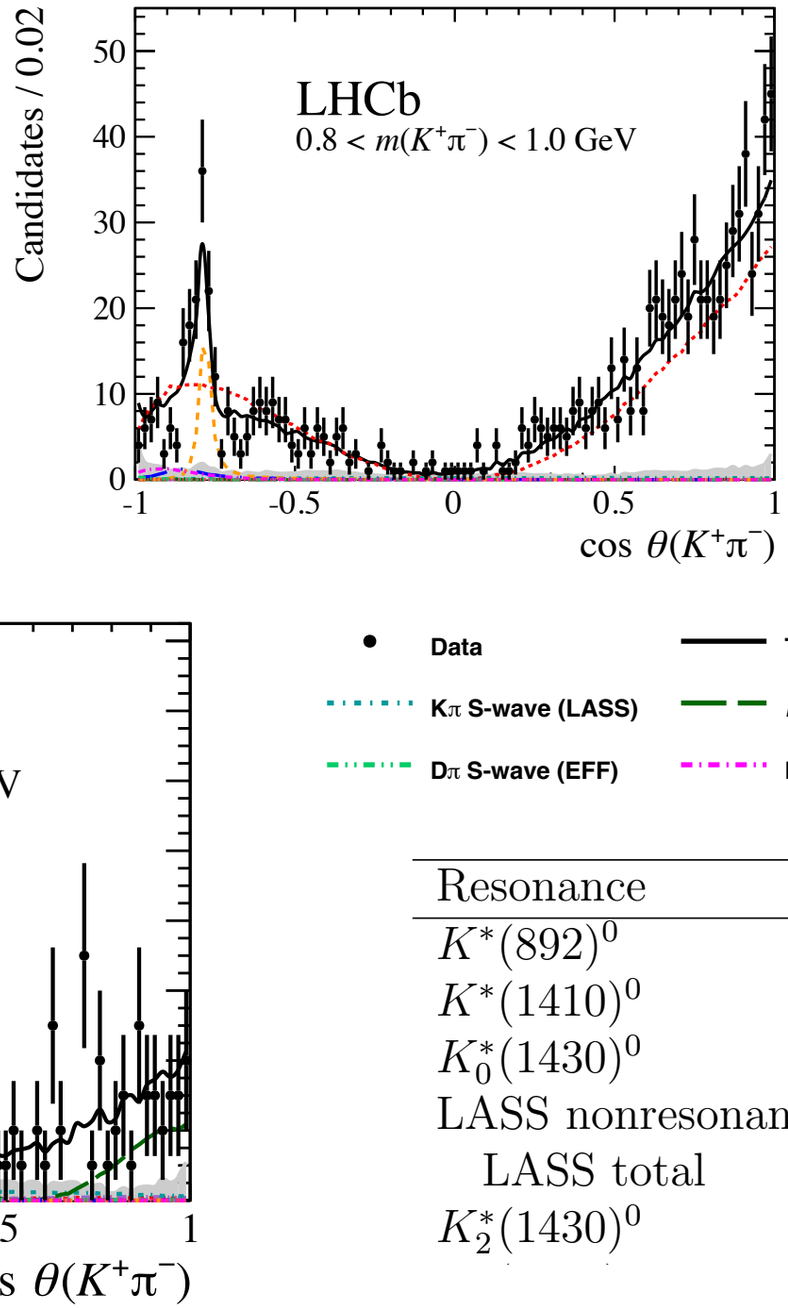
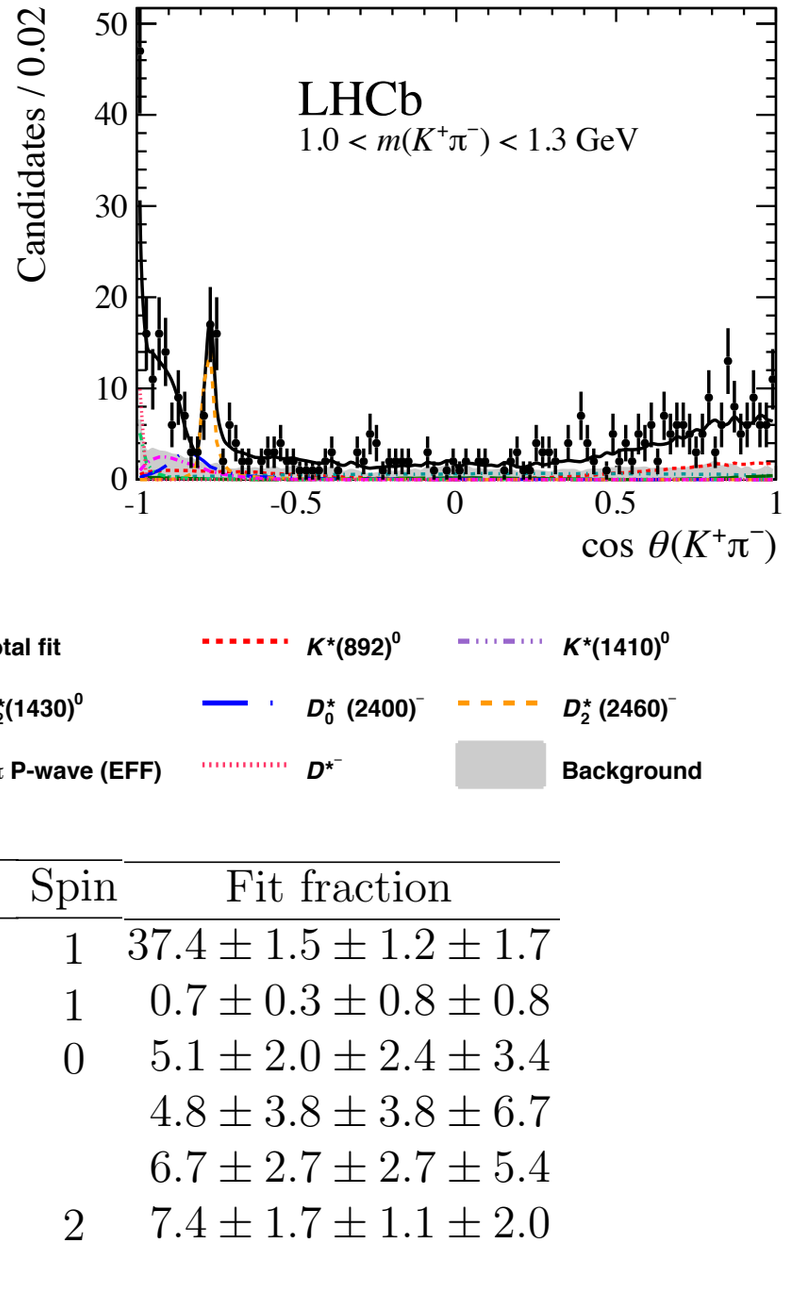
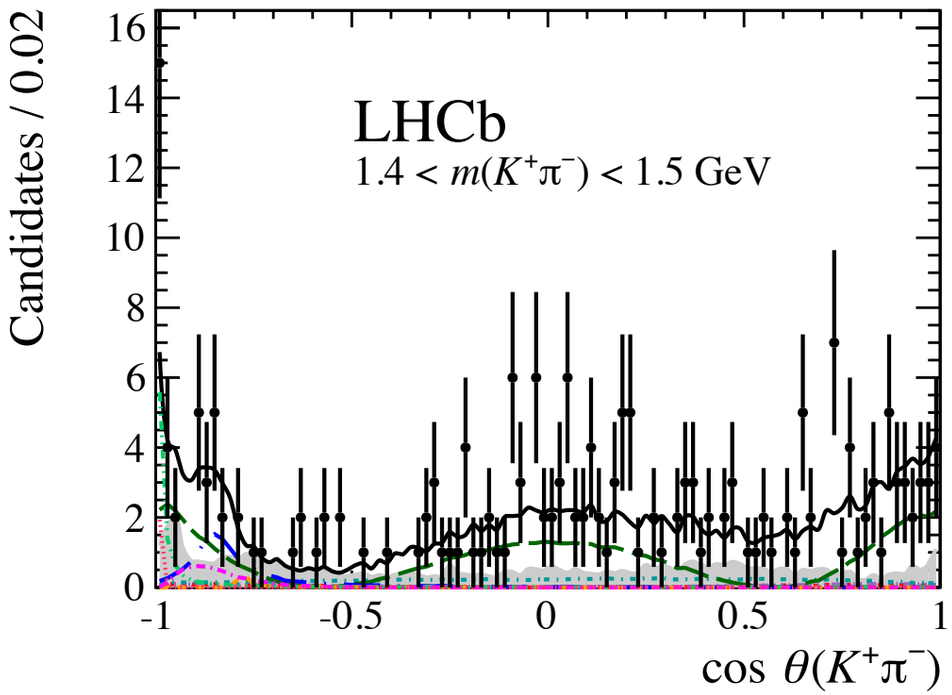
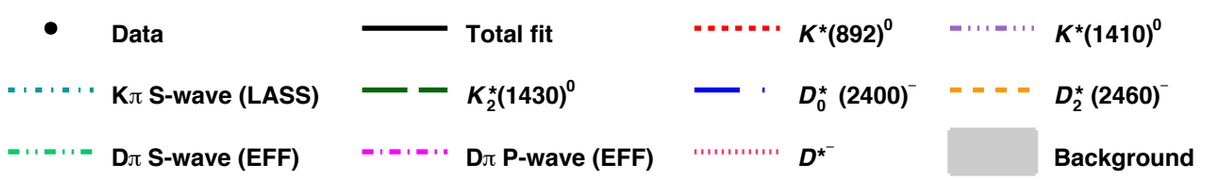










Resonance	Spin	Fit fraction
$K^*(892)^0$	1	$37.4 \pm 1.5 \pm 1.2 \pm 1.7$
$K^*(1410)^0$	1	$0.7 \pm 0.3 \pm 0.8 \pm 0.8$
$K_0^*(1430)^0$	0	$5.1 \pm 2.0 \pm 2.4 \pm 3.4$
LASS nonresonant		$4.8 \pm 3.8 \pm 3.8 \pm 6.7$
LASS total		$6.7 \pm 2.7 \pm 2.7 \pm 5.4$
$K_2^*(1430)^0$	2	$7.4 \pm 1.7 \pm 1.1 \pm 2.0$

m(Kπ) $B^0_s \to \bar{D}^0 K^- \pi^+$ vs $B^0 \to \bar{D}^0 K^+ \pi^-$

Universität Zürich[UZH]

LHCb PRD 90, 072003 (2014), PRD 92, 012012 (2015)

	$B^0_s \to \bar{D}^0 K^- \pi^+$	$B^0 \to \bar{D}^0 K^+ \pi^-$
Resonance	Branching fraction (10^{-4})	Branching fraction (10^{-5})
$K^*(892)^0$	$4.29 \pm 0.09 \pm 0.11 \pm 0.14 \pm 0.63$	$5.13 \pm 0.20 \pm 0.15 \pm 0.24 \pm 0.60$
$K^*(1410)^0$	$3.86 \pm 1.14 \pm 0.45 \pm 3.18 \pm 0.89$	$1.59 \pm 0.68 \pm 1.81 \pm 1.59 \pm 0.36$
$K^*_0(1430)^0$	$2.06 \pm 0.38 \pm 0.23 \pm 0.62 \pm 0.30$	$0.71 \pm 0.27 \pm 0.33 \pm 0.47 \pm 0.08$
LASS nonresonant	$3.00 \pm 0.24 \pm 0.11 \pm 0.50 \pm 0.44$	$0.66 \pm 0.51 \pm 0.51 \pm 0.92 \pm 0.08$
LASS total	$3.21 \pm 0.21 \pm 0.15 \pm 0.71 \pm 0.47$	$0.92 \pm 0.38 \pm 0.38 \pm 0.74 \pm 0.11$
$K^*_2(1430)^0$	$1.11 \pm 0.18 \pm 0.12 \pm 0.33 \pm 0.15$	$2.04 \pm 0.45 \pm 0.30 \pm 0.54 \pm 0.25$

- Interesting different relative rates of the spin-0 and spin-2 K^*'s between B^0/B^0_s
- Additional upper limits for B^0_s, *i.e.* $K^*(1680)$, $K^*_0(1950)$, $K^*_3(1780)$ and $K^*_4(2045)$
- Systematics uncertainties on the S-wave modelling given by probing alternative lineshapes, *i.e.* EFKLLM and κ + $K^*_0(1430)$

	$B^0_s \to \bar{D}^0 K^- \pi^+$	$B^0 \to \bar{D}^0 K^+ \pi^-$
Fit fractions LASS (%):	$21.4 \pm 1.4 \pm 1.0 \pm 4.7$	$6.7 \pm 2.7 \pm 2.7 \pm 5.4$

Add/remove resonances + alternative models

Universität Zürich[UZH]

Charmless three-body decays to final states containing a long-lived particle

---

LHCb results : $\mathcal{L} = 3\,\text{fb}^{-1}$ – 2011 + 2012 dataset

Updated branching fraction of $B^0_{(s)} \to K^0 h^+ h'^-$ decays

[JHEP 10 (2013) 143, JHEP 11 (2017) 027]

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

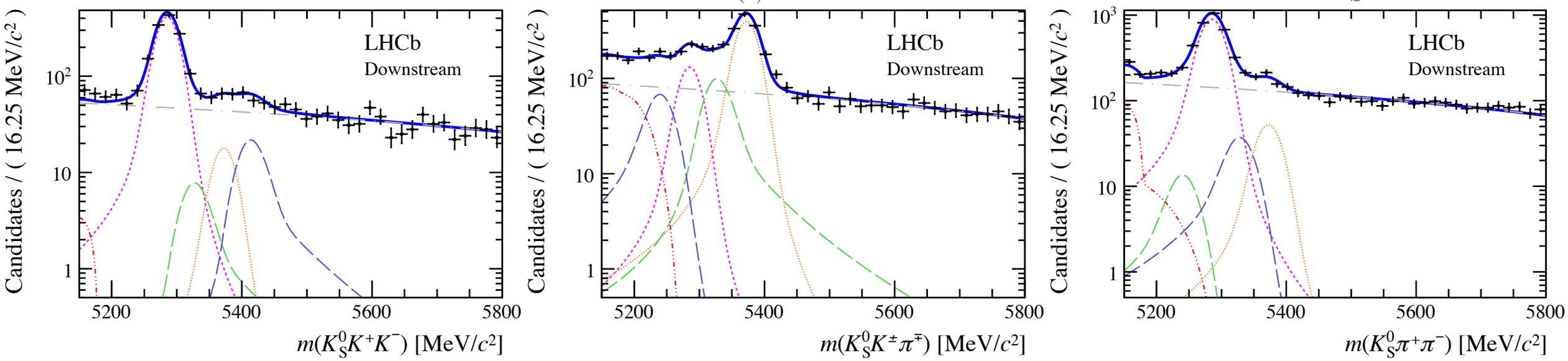
[LHCb-PAPER-2017-033, submitted to PRL]

LHCb

Recent results from $B^0_{(s)} \to K^0 h^+ h'^-$ decays

Universität Zürich[UZH]

LHCb JHEP 11 (2017) 027



- BF measurements of quasi-two-body states

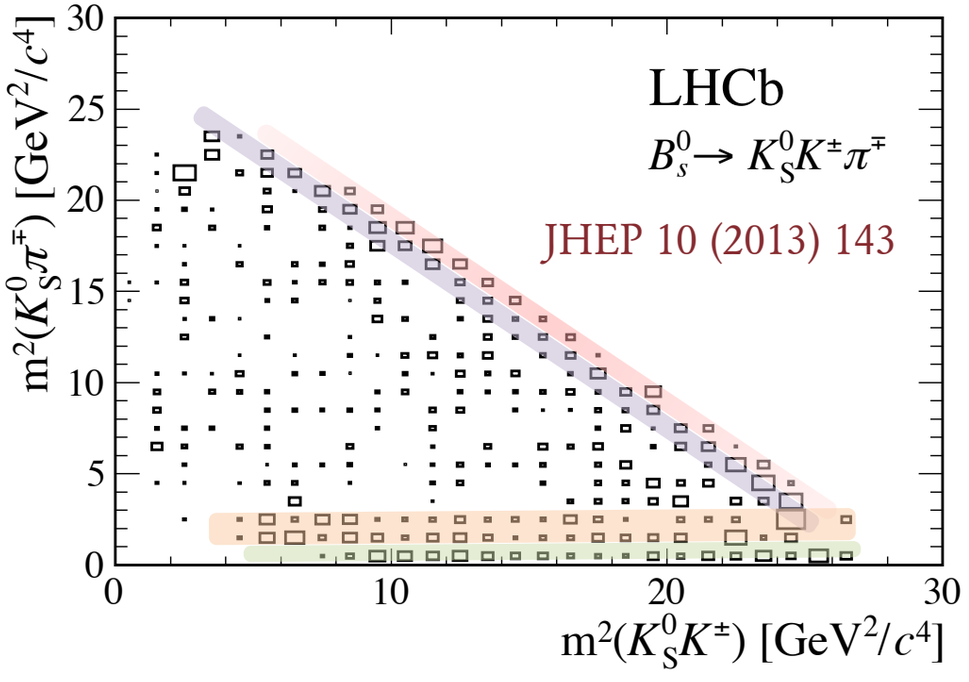
  [$B^0_s \to K^{*\pm} h^\mp$ - New J. Phys. 16 (2014) 123001]

  [$B^0_s \to K^{*0} K^0_S$ - JHEP 01 (2016) 012]

- Long term: time-dependent amplitude analysis for CKM-phases measurement

- Short term: time-integrated analysis

  [sensitive to ~~CP~~ in flavour-specific contributions]

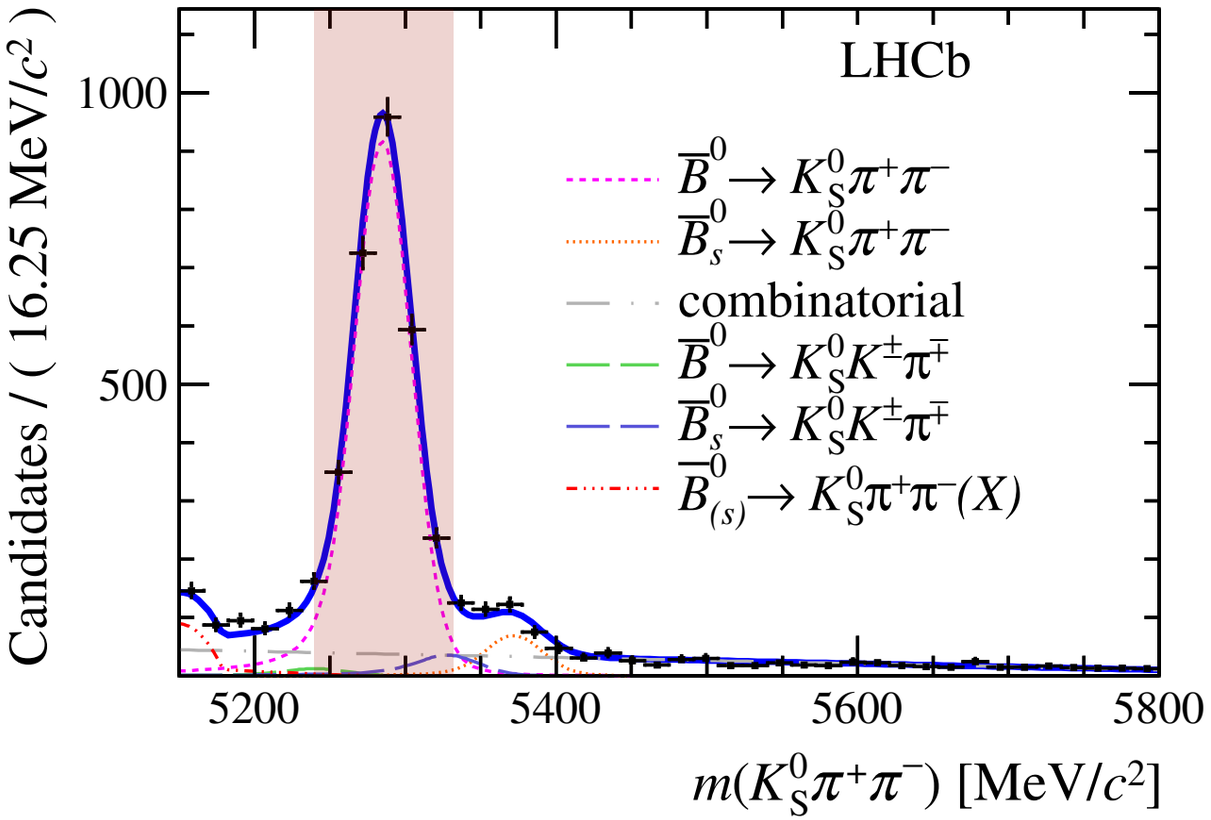


Dalitz plot analysis of $B^0 \to K^0\pi^-\pi^+$

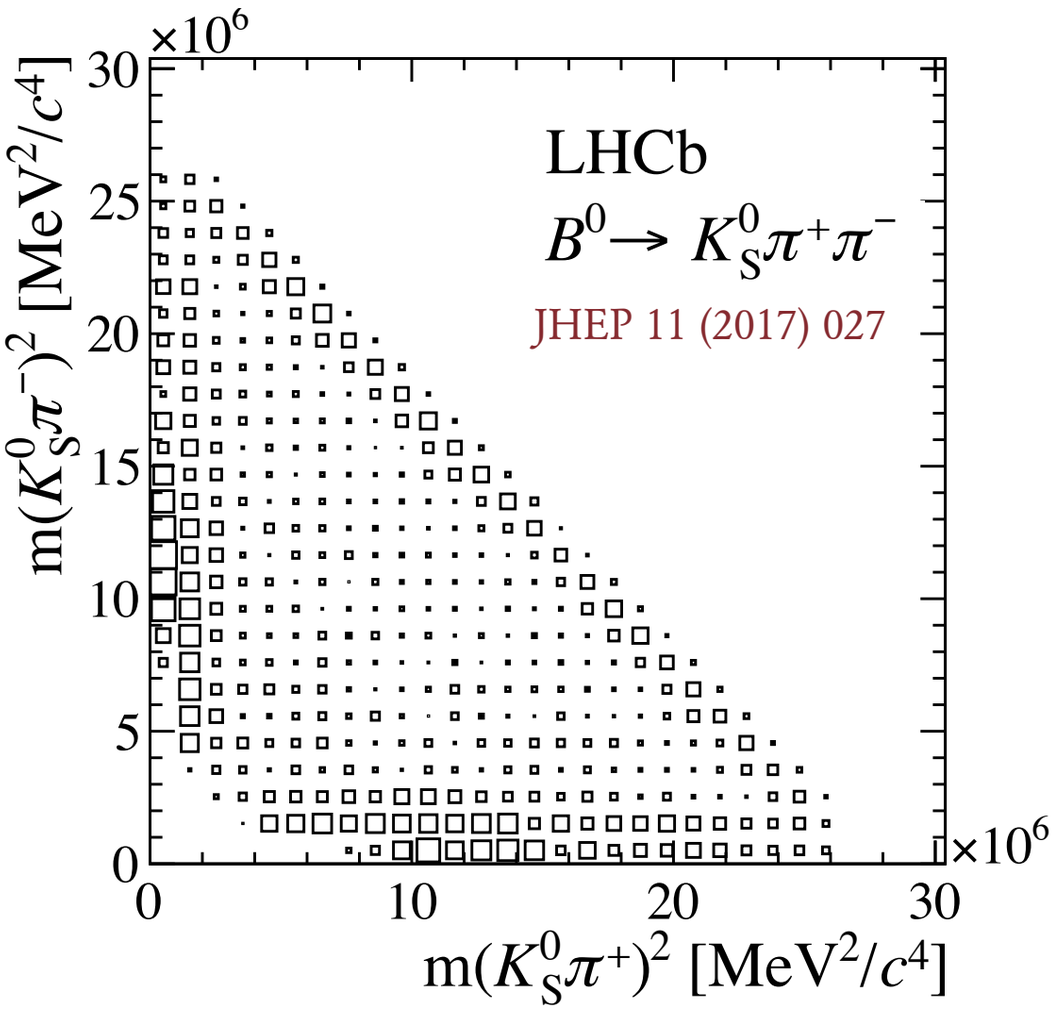
LHCb-PAPER-2017-033, submitted to PRL

Analysis performed with ~3.2K signal events and purity of 85-95%

Backgrounds due to Combinatorial (3-13%) and cross-feed (2-3%)



Signal region: ±3σ around nominal mass is considered for the Dalitz plot fit



Quasi-flavour-specific final state

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

Universität Zürich[UZH]

LHCb-PAPER-2017-033, submitted to PRL

Resonance	Parameters	Lineshape
$K^*(892)^-$	$m_0 = 891.66 \pm 0.26$ $\Gamma_0 = 50.8 \pm 0.9$	RBW
$(K\pi)_0^-$	$\mathcal{R}e(\lambda_0) = 0.204 \pm 0.103$ $\mathcal{I}m(\lambda_0) = 0$ $\mathcal{R}e(\lambda_1) = 1$ $\mathcal{I}m(\lambda_1) = 0$	EFKLLM
$K_2^*(1430)^-$	$m_0 = 1425.6 \pm 1.5$ $\Gamma_0 = 98.5 \pm 2.7$	RBW
$K^*(1680)^-$	$m_0 = 1717 \pm 27$ $\Gamma_0 = 332 \pm 110$	Flatté
$f_0(500)$	$m_0 = 513 \pm 32$ $\Gamma_0 = 335 \pm 67$	RBW
$\rho(770)^0$	$m_0 = 775.26 \pm 0.25$ $\Gamma_0 = 149.8 \pm 0.8$	GS
$f_0(980)$	$m_0 = 965 \pm 10$ $g_\pi = 0.165 \pm 0.025$ GeV $g_K = 0.695 \pm 0.119$ GeV	Flatté
$f_0(1500)$	$m_0 = 1505 \pm 6$ $\Gamma_0 = 109 \pm 7$	RBW
χ_{c0}	$m_0 = 3414.75 \pm 0.31$ $\Gamma_0 = 10.5 \pm 0.6$	RBW
Nonresonant (NR)		Phase space

EFKLLM: $R_j(m) = F(m)\left(\frac{\lambda_0}{m^2} + \lambda_1\right)$

Asymmetry observable derived from usual isobar parameters

$$\mathcal{A}_{\text{raw}} = \frac{|\overline{c}_j|^2 - |c_j|^2}{|\overline{c}_j|^2 + |c_j|^2}$$

The CP asymmetry is related to the raw asymmetry by $\mathcal{A}_{CP} = \mathcal{A}_{\text{raw}} - \mathcal{A}_\Delta$

PRL 110 (2013) 221601, PLB 713 (2012) 186

$$\mathcal{A}_\Delta = A_P(B^0) + A_D(\pi)$$

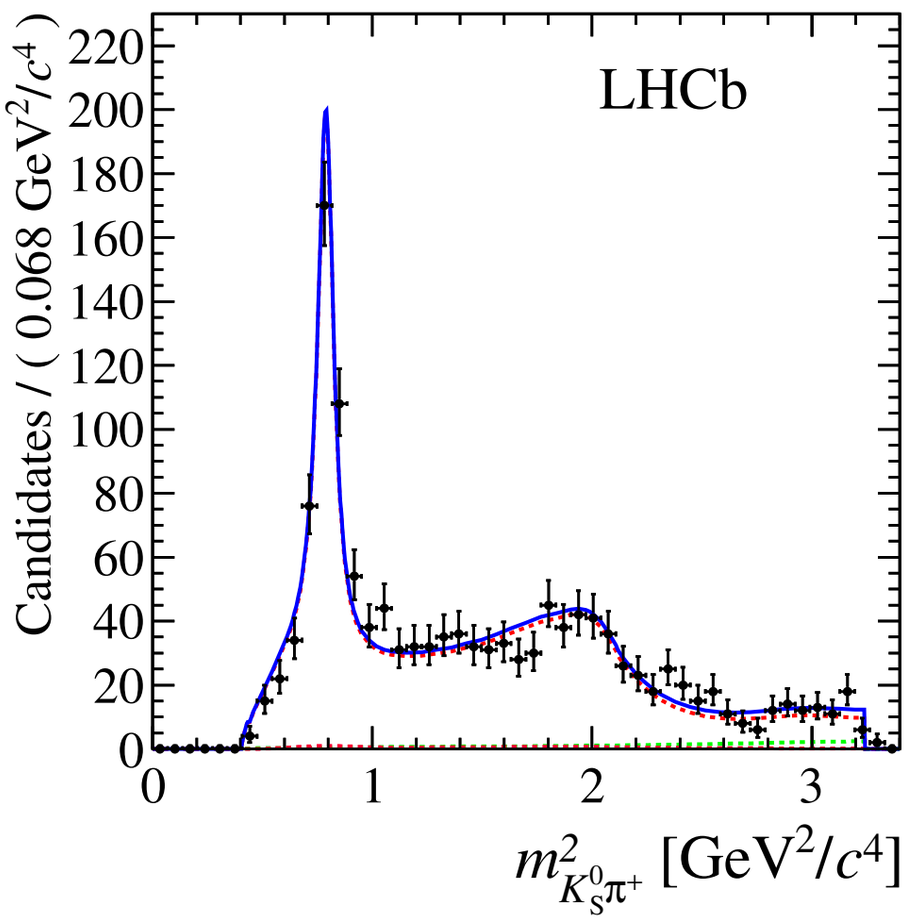
(-0.35 ± 0.81)% 0.25%

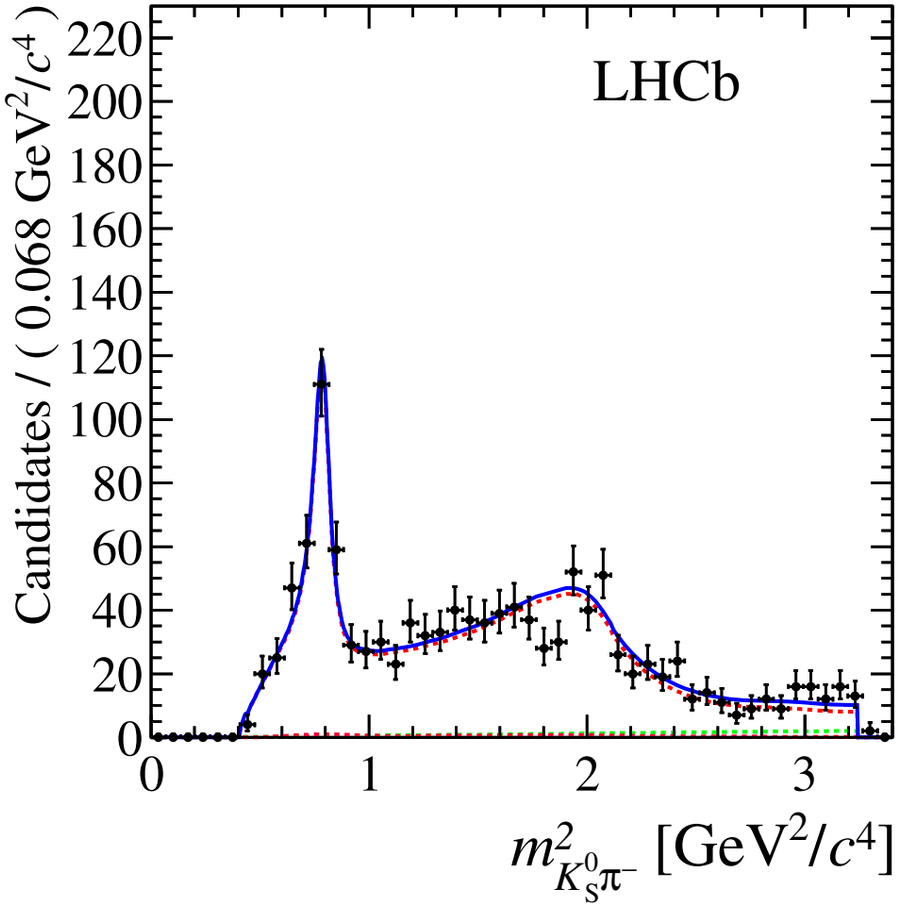
Fit fractions:

$$\mathcal{F}_i = \frac{\int\int_{\text{DP}} |c_i F_i(s_+, s_-)|^2 \, \mathrm{d}s_+ \mathrm{d}s_-}{\int\int_{\text{DP}} \left|\sum_j c_j F_j(s_+, s_-)\right|^2 \mathrm{d}s_+ \mathrm{d}s_-}$$

Dalitz plot fit results

LHCb-PAPER-2017-033, submitted to PRL





$\mathcal{A}_{CP}(K^*(892)^-\pi^+)$	$= -0.308 \pm 0.060 \pm 0.011 \pm 0.012$
$\mathcal{A}_{CP}((K\pi)_0^-\pi^+)$	$= -0.032 \pm 0.047 \pm 0.016 \pm 0.027$
$\mathcal{A}_{CP}(K_2^*(1430)^-\pi^+)$	$= -0.29 \pm 0.22 \pm 0.09 \pm 0.03$
$\mathcal{A}_{CP}(K^*(1680)^-\pi^+)$	$= -0.07 \pm 0.13 \pm 0.02 \pm 0.03$
$\mathcal{A}_{CP}(f_0(980)K^0_S)$	$= 0.28 \pm 0.27 \pm 0.05 \pm 0.14$

First observation of *CP* violation in $B^0 \to K^*(892)\pi$ with ~ 6 sigma

World average

$\mathcal{A}(K^*(892)\pi) = -0.23 \pm 0.06$

Dalitz plot fit results

LHCb-PAPER-2017-033, submitted to PRL

Fit fractions:

$$
\begin{aligned}
\mathcal{F}(K^*(892)^-\pi^+) &= 9.43 \pm 0.40 \pm 0.33 \pm 0.34\ \% \\
\mathcal{F}((K\pi)^-_0\pi^+) &= 32.7 \pm 1.4 \pm 1.5 \pm 1.1\ \% \\
\mathcal{F}(K^*_2(1430)^-\pi^+) &= 2.45\ ^{+\ 0.10}_{-\ 0.08} \pm 0.14 \pm 0.12\ \% \\
\mathcal{F}(K^*(1680)^-\pi^+) &= 7.34 \pm 0.30 \pm 0.31 \pm 0.06\ \% \\
\mathcal{F}(f_0(980)K^0_S) &= 18.6 \pm 0.8 \pm 0.7 \pm 1.2\ \% \\
\mathcal{F}(\rho(770)^0K^0_S) &= 3.8\ ^{+\ 1.1}_{-\ 1.6} \pm 0.7 \pm 0.4\ \% \\
\mathcal{F}(f_0(500)K^0_S) &= 0.32\ ^{+\ 0.40}_{-\ 0.08} \pm 0.19 \pm 0.23\ \% \\
\mathcal{F}(f_0(1500)K^0_S) &= 2.60 \pm 0.54 \pm 1.28 \pm 0.60\ \% \\
\mathcal{F}(\chi_{c0}K^0_S) &= 2.23\ ^{+\ 0.40}_{-\ 0.32} \pm 0.22 \pm 0.13\ \% \\
\mathcal{F}(K^0_S\pi^+\pi^-)^{\rm NR} &= 24.3 \pm 1.3 \pm 3.7 \pm 4.5\ \%
\end{aligned}
$$

- The resonance state K*(1680) has been included in the model (not used in previous analyses)

Belle PRD 79 (2009) 072004, BaBar PRD 80 (2009) 112001

- Alternative LASS modelling for the S-wave has been examined:

$$-2\Delta \ln \mathcal{L} = 85$$

No systematic is assigned to the choice of the model, but only uncertainties associated to fixed parameters

Universität Zürich[UZH]

Status/issues foreseen for CPV measurements in charmless three-body decays

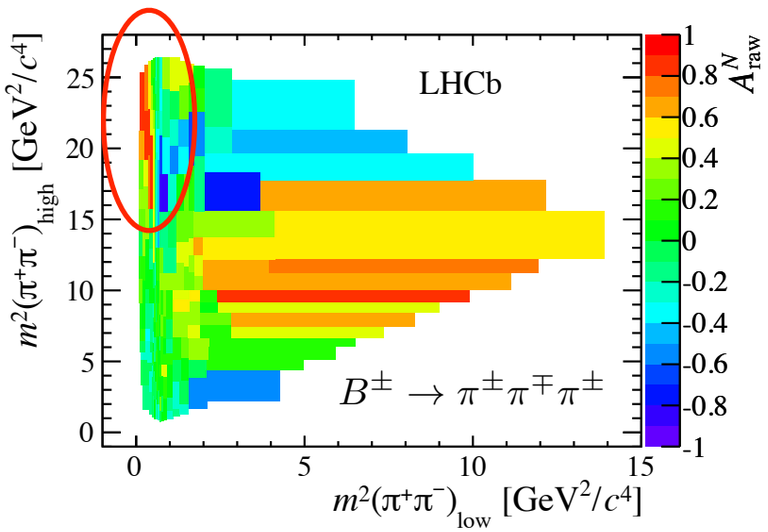
LHCb $\mathcal{L} = 3\,\mathrm{fb}^{-1}$ – 2011 + 2012 dataset

Prospects for Dalitz-plot analyses

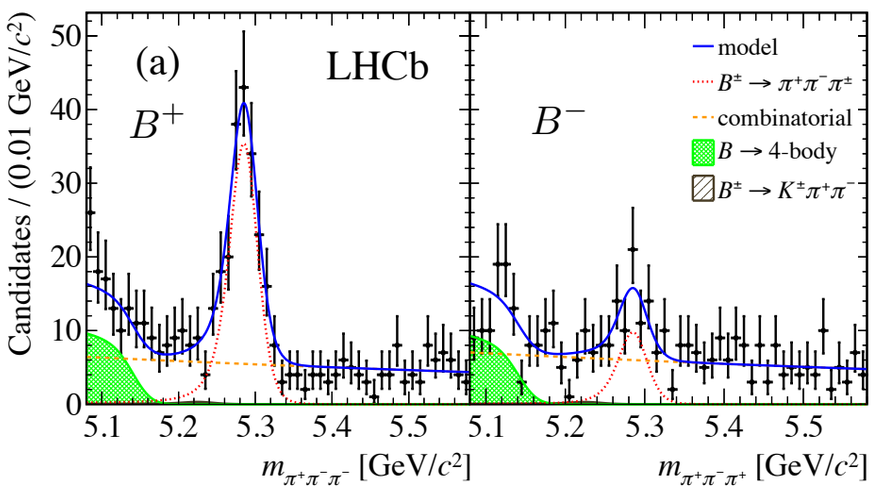
Towards [more] charmless DP analyses

LHCb PRD 90, 112004 (2014), PRL 112 (2014) 011801, PRL 111 (2013) 101801

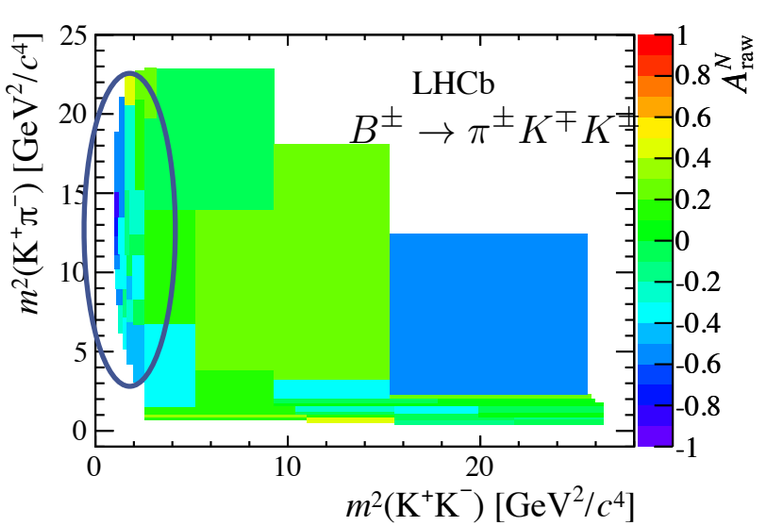
Efforts on understanding the large asymmetries seen in $B^+ \to h^+h^-h^+$ decays



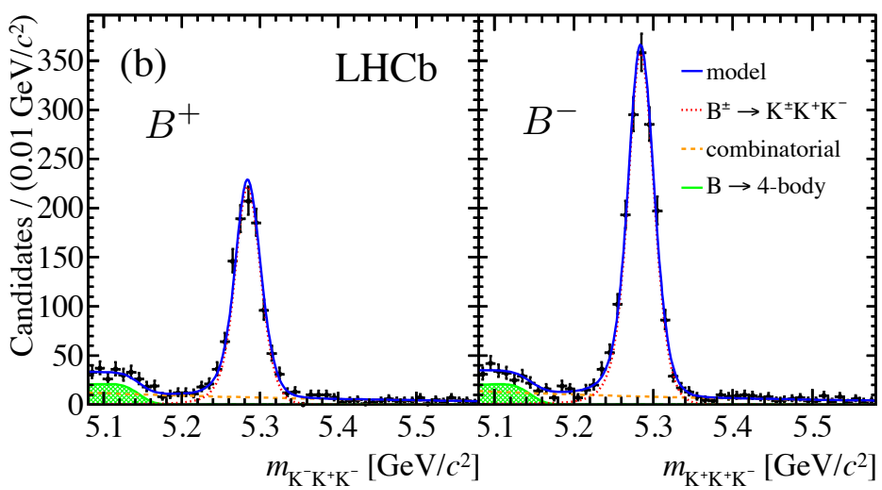
$m^2_{\pi^+\pi^-\,\rm low} < 0.4\,\mathrm{GeV}^2/\mathrm{c}^4$ and $\mathrm{m}^2_{\pi^+\pi^-\,\rm high} > 15\,\mathrm{GeV}^2/\mathrm{c}^4$



$$\mathcal{A}^{CP}_{\rm reg}(B^\pm \to \pi^\pm\pi^+\pi^-) = 0.584 \pm 0.082 \pm 0.027 \pm 0.007$$

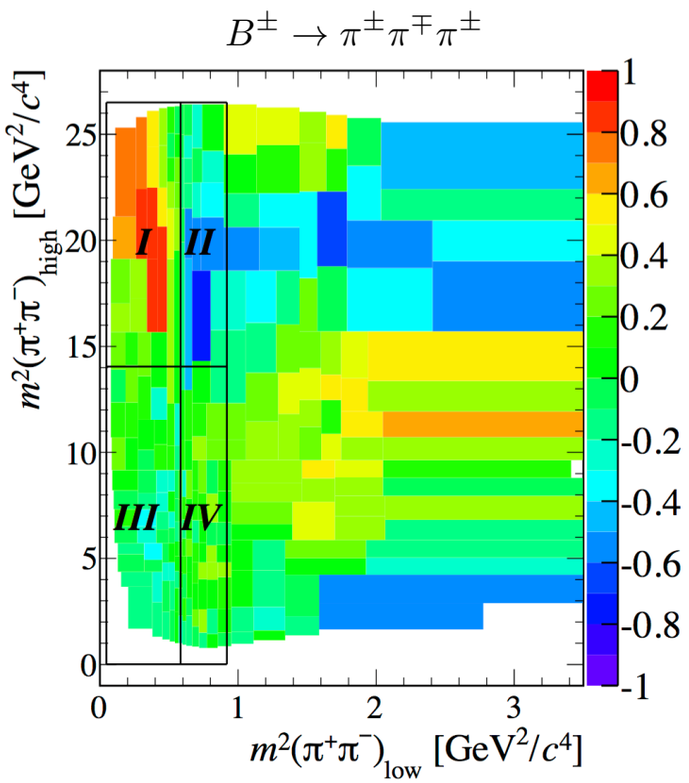


$m^2_{K^+K^-} < 1.5\,\mathrm{GeV}^2/\mathrm{c}^4$



$$\mathcal{A}^{CP}_{\rm reg}(B^\pm \to \pi^\pm K^+ K^-) = -0.648 \pm 0.070 \pm 0.013 \pm 0.007$$

Towards [more] charmless DP analyses



Sign of A^{CP} (e.g. regions I-II) indicate interference between S- and P-wave importance

Re-scattering may also play a role in the region between 1 and 1.5 GeV

LHCb PRD 90, 112004 (2014)

- DP analysis is clearly required, in particular to understand the origin of the strong phase difference
- **Such analyses are currently ongoing at LHCb!**

  [*i.e.* (1) $B^\pm \to \pi^\pm\pi^\mp\pi^\pm$, (2) $B^\pm \to \pi^\pm K^+K^-$ ...]

- Unprecedented statistics (*e.g.* 5-200 K events for $B^\pm \to \pi^\pm K^+K^-$, $K^\pm\pi^+\pi^-$): simplified theoretical descriptions are no longer sufficient
  - How to model non-resonant contributions, final state interaction, re-scattering effects? Connect two (or all) different final states?
  - How to obtain an accurate description of the S-wave?

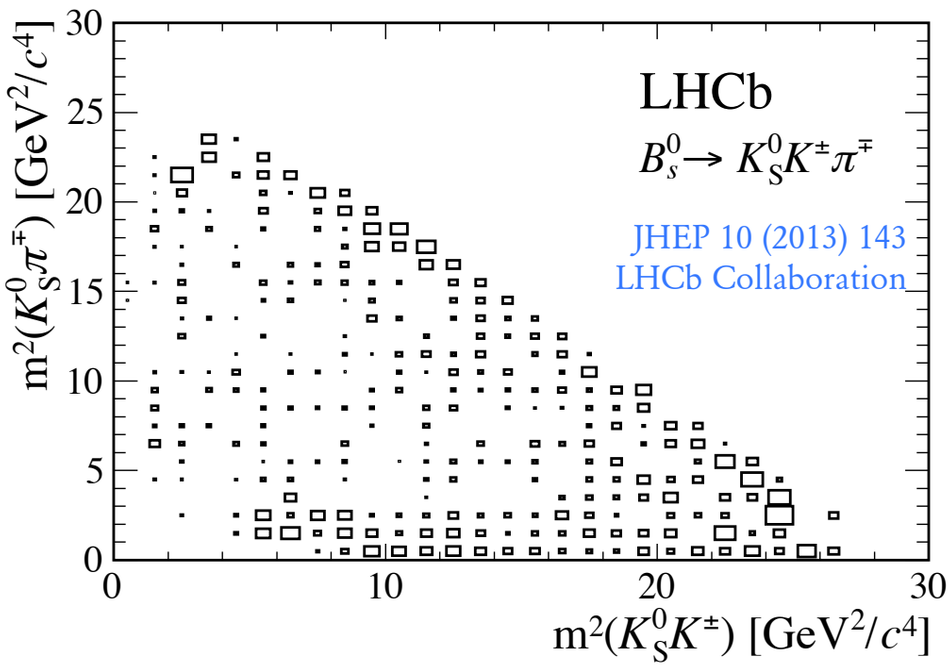
    [*e.g.* for $B^\pm \to \pi^\pm K^+K^-$ already limited, NR+ $K^*_0(1430)$ or κ + $K^*_0(1430)$?]

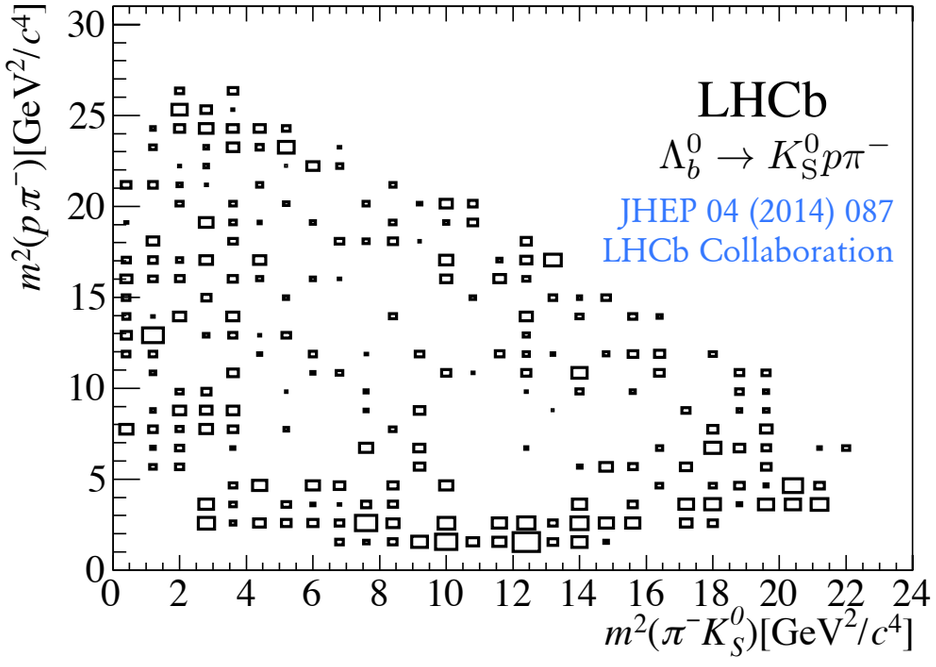
Towards [more] charmless DP analyses

Many other channels that have never been explored in the B-factories are gradually being investigated

- Untagged time-integrated analysis of $B^0_s \to K^0_S K\pi$ decays
  - Only flavour averaged fit fractions
  - Modelling of S-wave of crucial relevance, *i.e.* LASS/EFKLLM
- Amplitude analysis of $\Lambda_b \to K^0_S p\pi^-$
  - Large $A_{CP}(pK^*) \sim 20\%$ predicted

[PRD 91 (2015) 11, 116007]





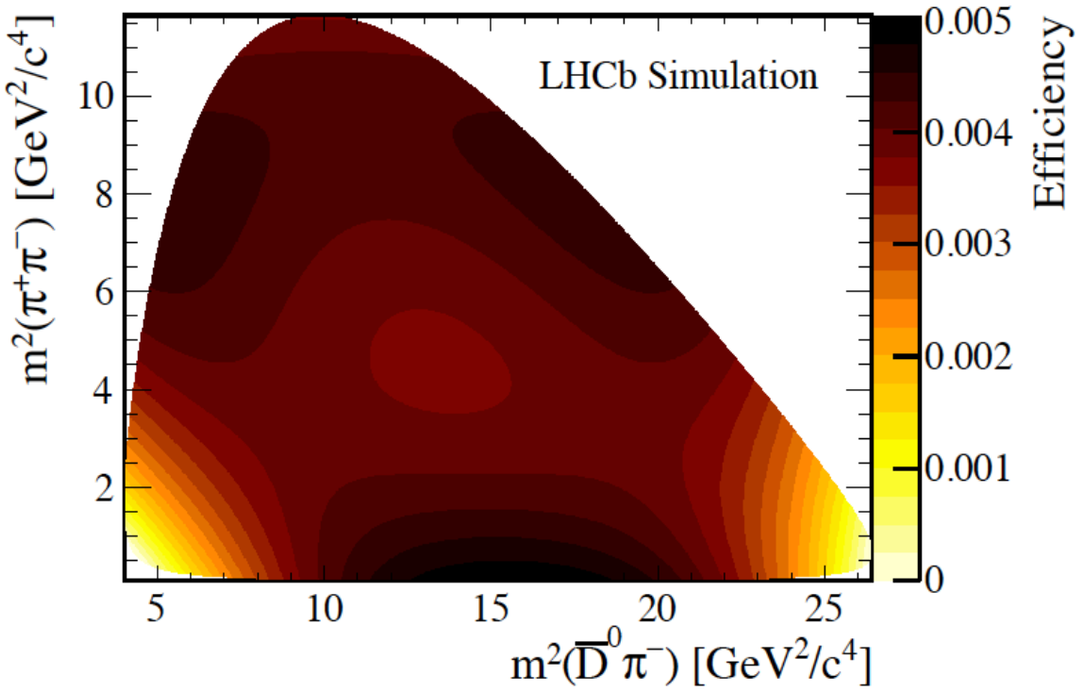
General conclusions

- Enormous wealth of physics to be found in three-body hadronic decays of b-hadrons (*e.g.* Spectroscopy, CP violation)
- Note that LHCb has also a large programme of Dalitz plot analyses in D mesons [*e.g.* LASS vs GLASS in $D^0 \to K^0_S K\pi$; PRD 93, 052018 (2016)]
- Of course, not only DP analyses, *e.g.* $B^0 \to [K\pi]_J\, l^+l^-$, $B^0_s \to [K\pi][K\pi]$
- Some very interesting and intriguing results obtained recently in B to open-charm and charmless decays
  - However, many open questions on how to properly model the $K\pi$ system. Unprecedented statistics will require a better understanding
  - Larger datasets from the LHCb Run-II+ upgrade will provide in the future the possibility to fully explore the potential of the field

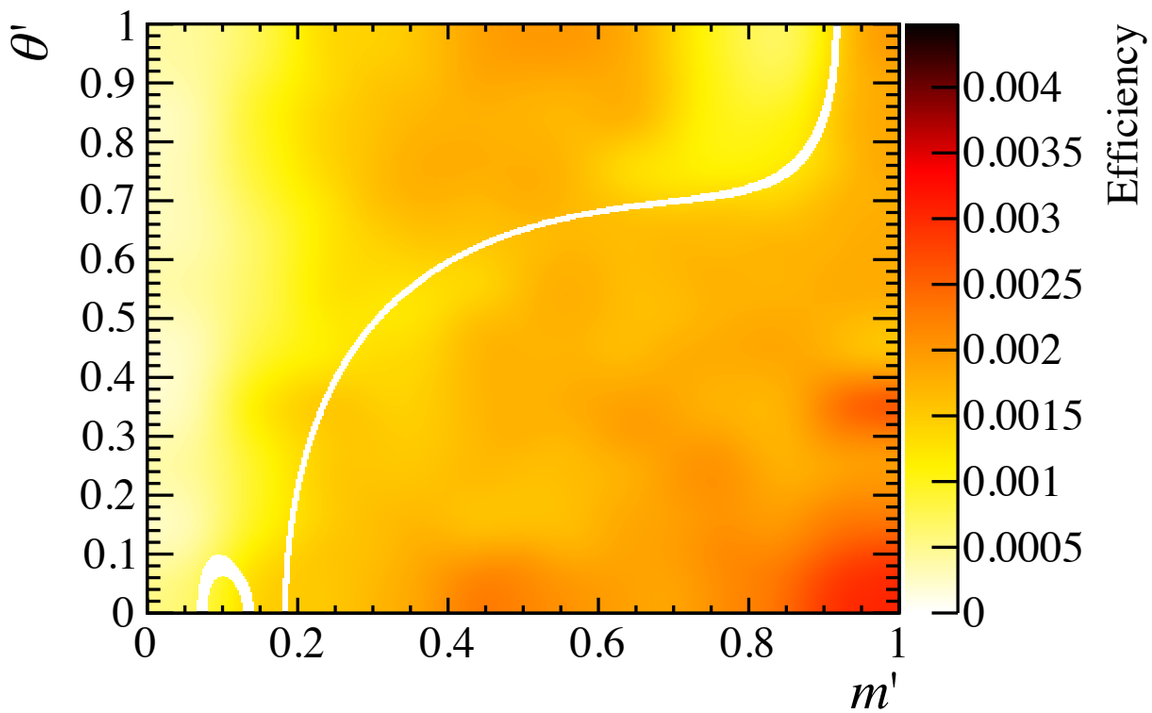
Detector acceptance modelling

Since each detector has its own acceptance, such effects need to be properly accommodated when performing a Dalitz plot fit

- Two general approaches: 2-D polynomial (or similar) function or a 2-D histogram



$$\mathcal{L} = \prod_{l=1}^{N_{evts}} \frac{\epsilon(m_{ij}^2, m_{jk}^2) \left| \sum_{m=1}^{N_R} c_m F_m(m_{ij}^2, m_{jk}^2) \right|^2}{\int_{DP} \epsilon(m_{ij}^2, m_{jk}^2) \left| \sum_{m=1}^{N_R} c_m F_m(m_{ij}^2, m_{jk}^2) \right|^2 dDP}$$

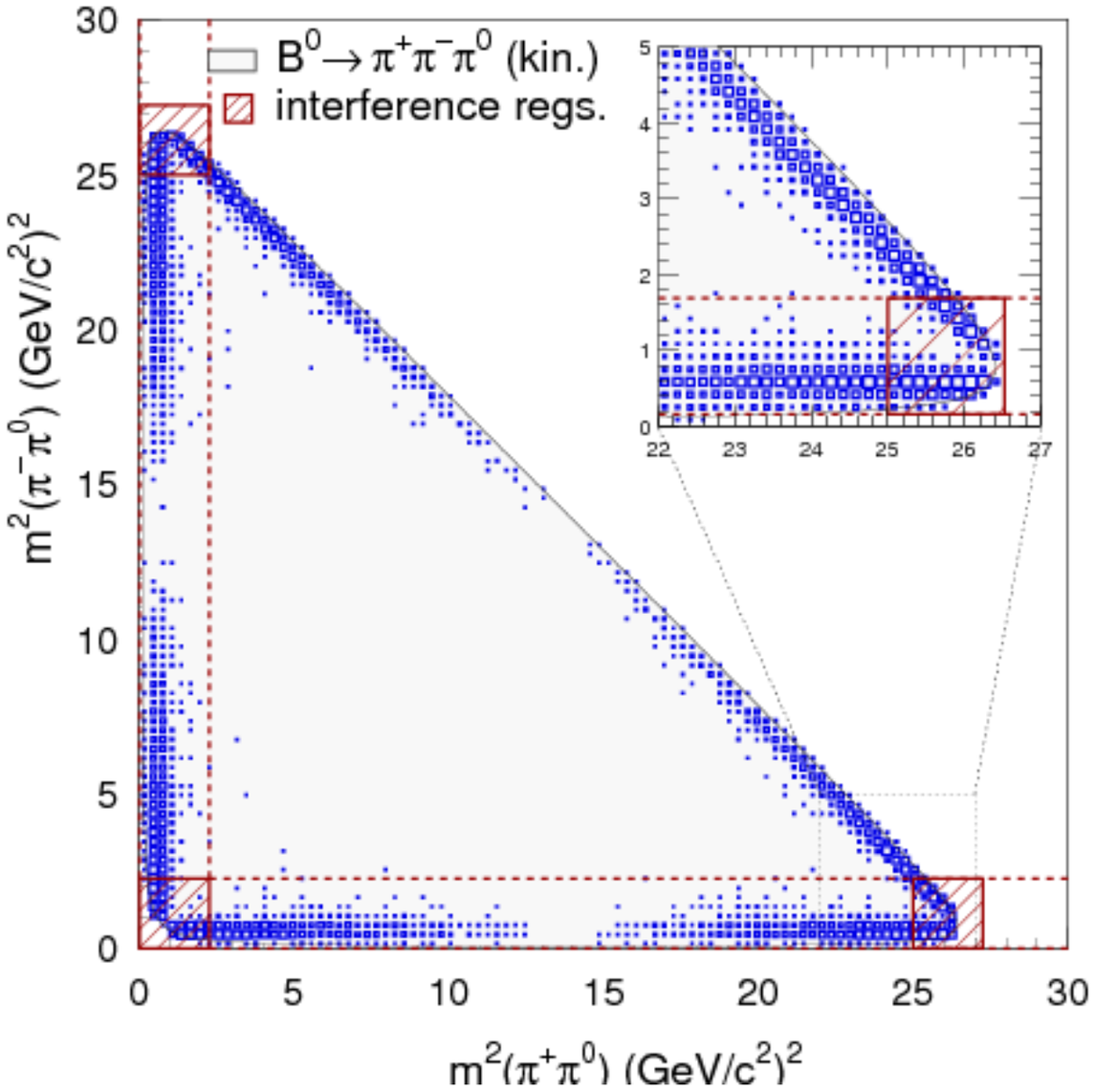


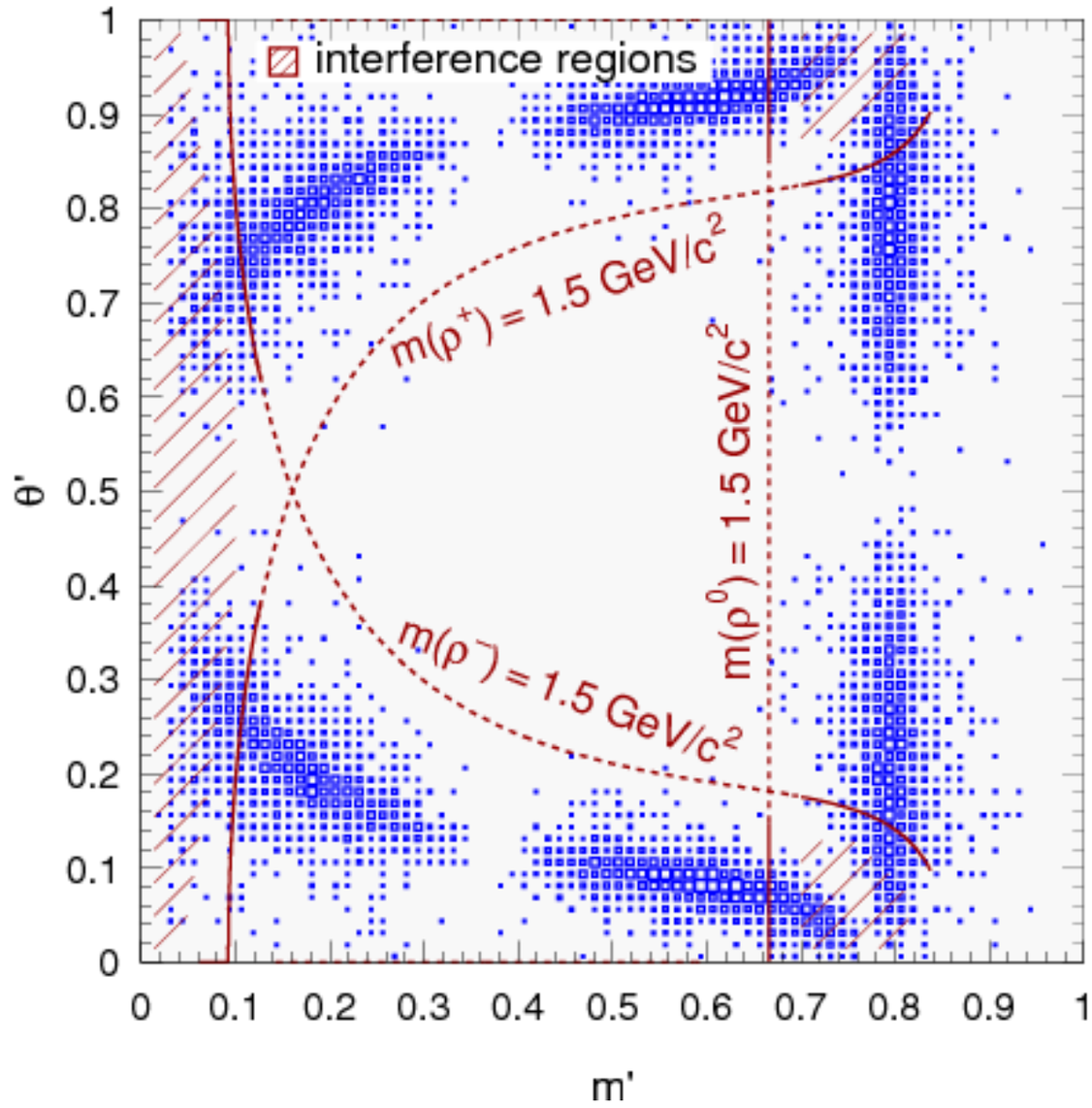
LHCb general strategy has been based on Spline these distributions in the squared DP

[Backup]

Detector acceptance modelling

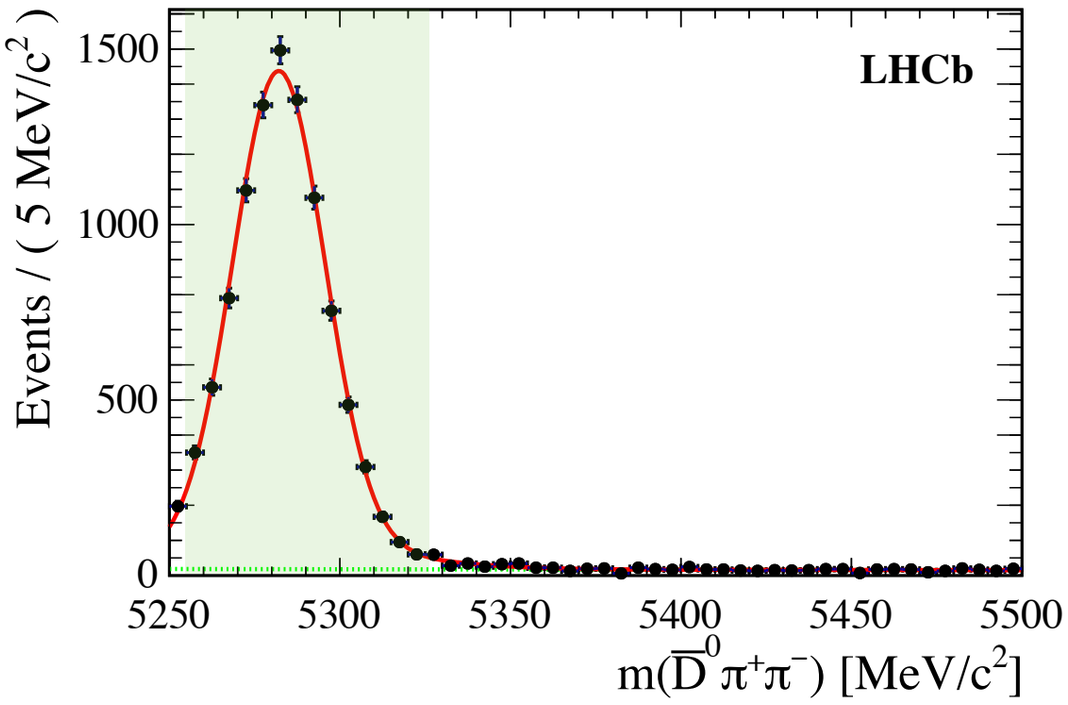
Preferential co-ordinate transformation to improve sensitivity modelling in the DP borders

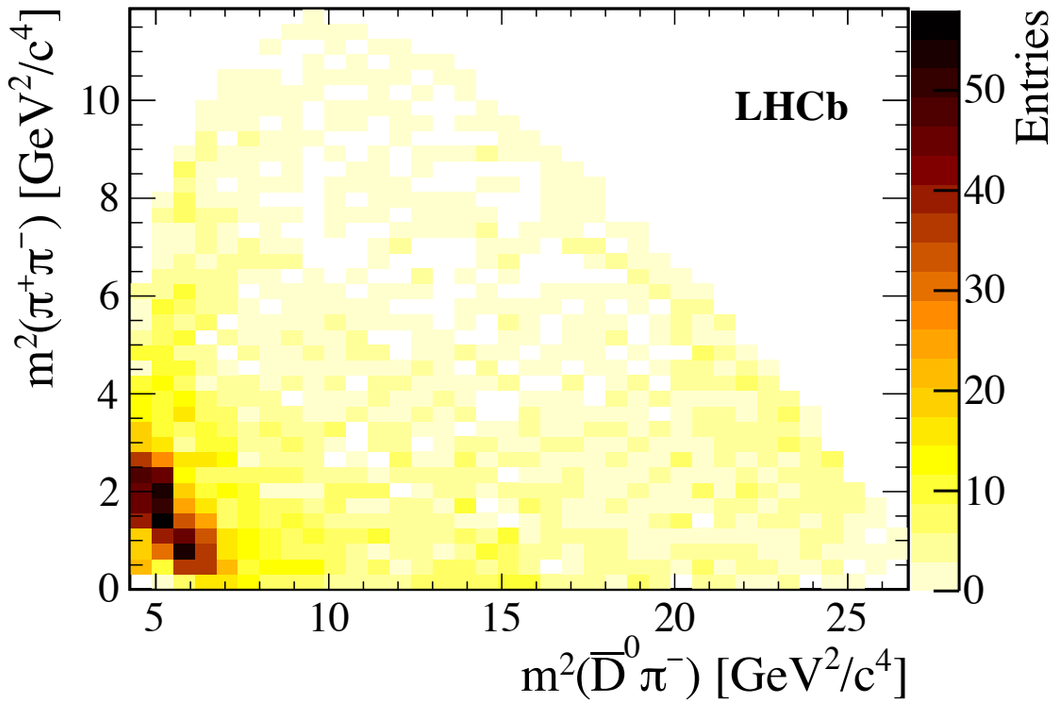




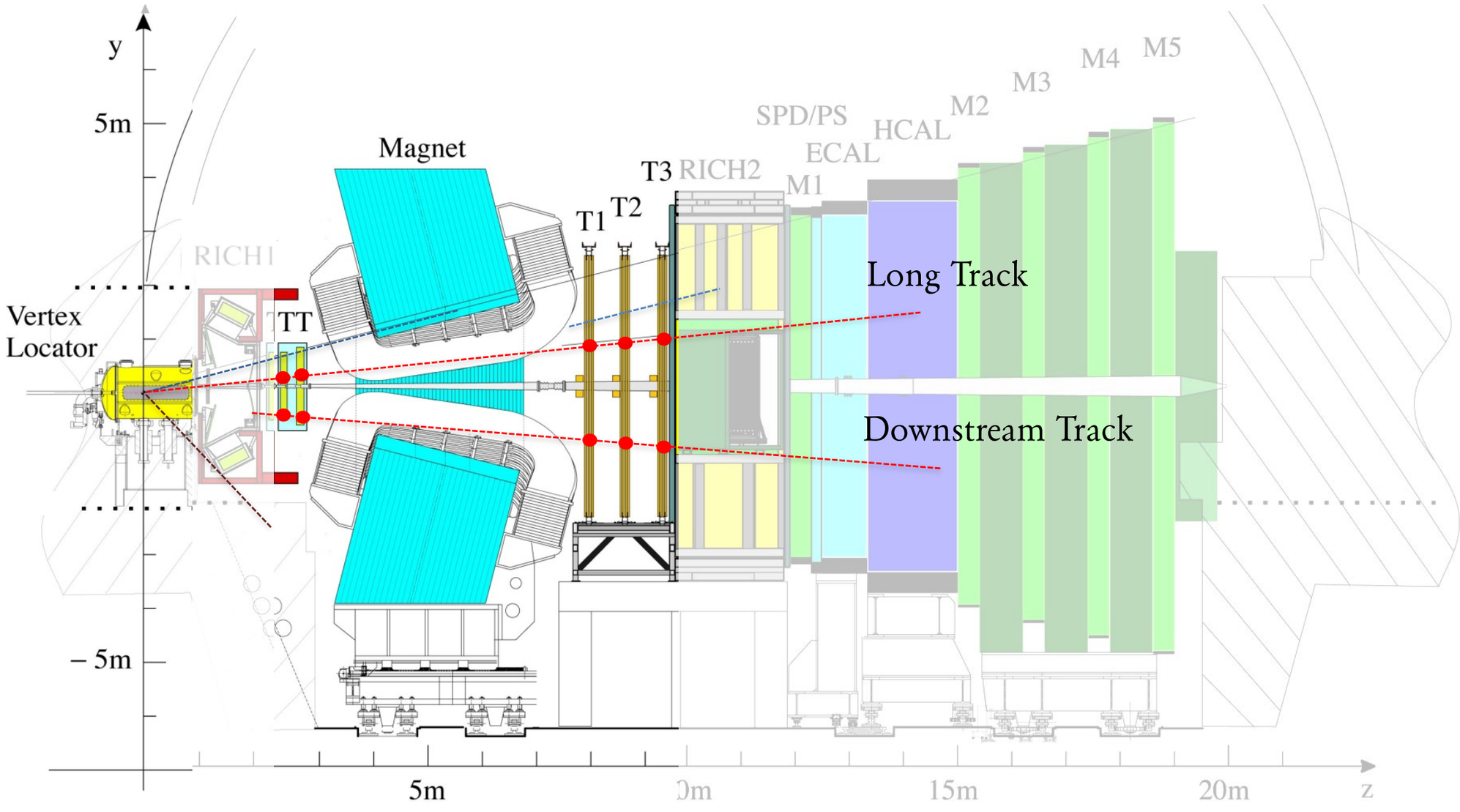
Background contributions

Contributions from different backgrounds can be presented and need to be modelled





$$\mathcal{L} = \prod_{l=1}^{N_{evts}} \left[\frac{\epsilon(m_{ij}^2, m_{jk}^2) \left| \sum_{m=1}^{N_R} c_m F_m(m_{ij}^2, m_{jk}^2) \right|^2}{\int_{DP} \epsilon(m_{ij}^2, m_{jk}^2) \left| \sum_{m=1}^{N_R} c_m F_m(m_{ij}^2, m_{jk}^2) \right|^2 dDP} + \frac{\sum_{m=1}^{N_B} |k_m|^2 |B_m(m_{ij}^2, m_{jk}^2)|^2}{\int_{DP} \sum_{m=1}^{N_B} |k_m|^2 |B_m(m_{ij}^2, m_{jk}^2)|^2 dDP} \right]$$

Signal (Coherent) **Background (Incoherent)**

How LHCb reconstruct K^0 mesons?