CP violation in charmless three-body $B^{\pm}$ decays

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on behalf of the LHCb collaboration

PHENOEXP 2018

ICAS, Buenos Aires, 9 May 2018

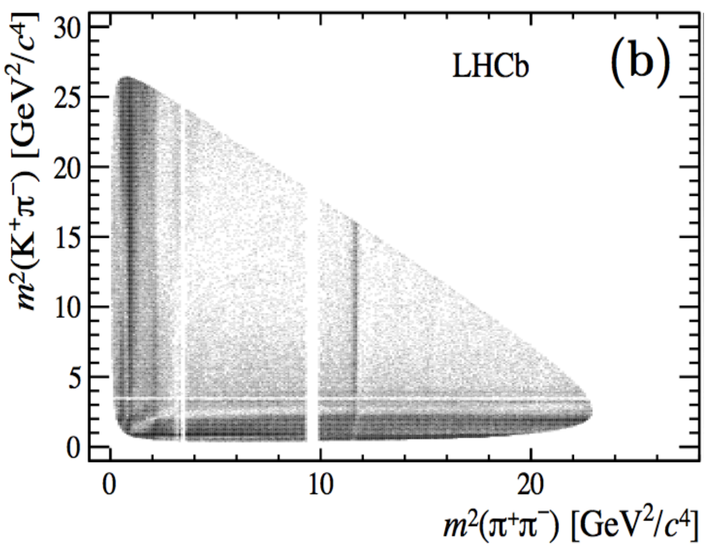
Charmless three-body B decays

Charmless B-meson decays:

- Are suppressed in the SM and can be sensitive to New Physics.
- Proceed via tree- and loop-level diagrams with similar magnitudes and relative weak and strong phases, which can lead to direct CP violation: $\left|\frac{\bar{A}}{A}\right| \neq 1$
- New Physics could provide additional sources of CPV.

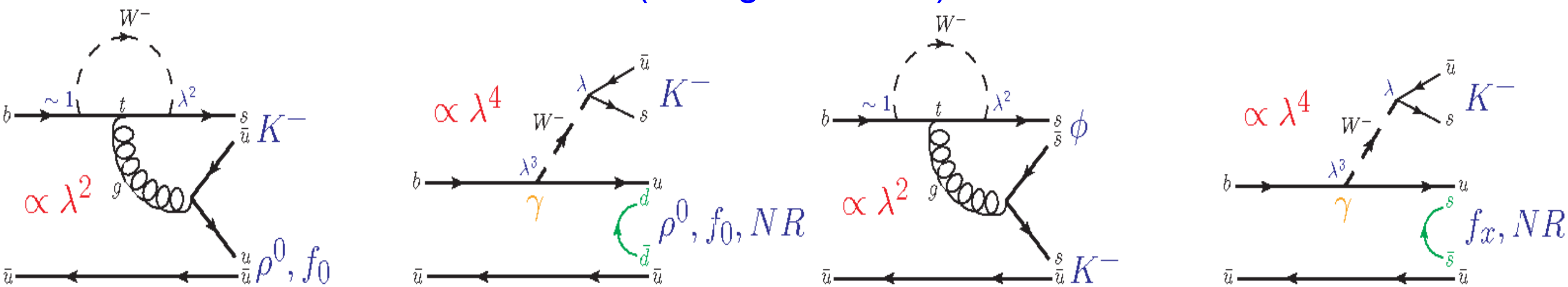
Three-body B-meson decays:

- Can proceed via intermediate two-body resonant states.
- There are 2 degrees of freedom in the phase space of decays to 3 scalar particles.
- The invariant masses m_{23} and m_{31} form the Dalitz plot.



$B^{\pm} \rightarrow \pi^{+}\pi^{-}K^{\pm}$, $K^{+}K^{-}K^{\pm}$ decays

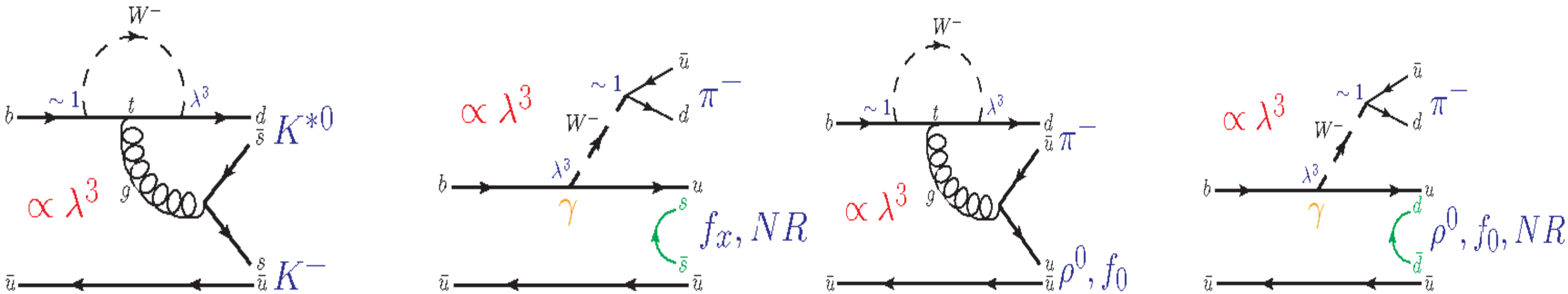
$B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ (strangeness = 1) $B^{\pm} \rightarrow K^{\pm}K^{+}K^{-}$



- Contributions from penguin ($b \rightarrow s$) and tree ($b \rightarrow u$) transitions.
- CPV expected from interference between tree and penguin diagrams.
- CPV expected from intermediate two-body resonant states.
  - → Evidence of CPV in $B^{\pm} \rightarrow \rho K^{\pm}$. Belle: PRL **96**, (2006) 251803; BaBar: PR **D78**, (2008) 012004
  - → Evidence of CPV in $B^{\pm} \rightarrow \phi K^{\pm}$ (not confirmed by LHCb). BaBar: PR **D85**, (2012) 112010
- CPT connection means possibility of "compound" CPV ($KK \leftrightarrow \pi\pi$ rescattering). Cheng, Chua, Soni, PR **D71** (2005) 014030;
- CPT: the sum of the partial decay widths, for all channels with the same quantum numbers, be equal for charge-conjugated decays. Bediaga, Frederico, Lourenço, PRD 89 094013 (2014)

$B^\pm \longrightarrow K^+K^-\pi^\pm, \pi^+\pi^-\pi^\pm$ decays

$B^\pm \longrightarrow K^\pm K^+\pi^-$ (strangeness = 0) $B^\pm \longrightarrow \pi^\pm\pi^+\pi^-$



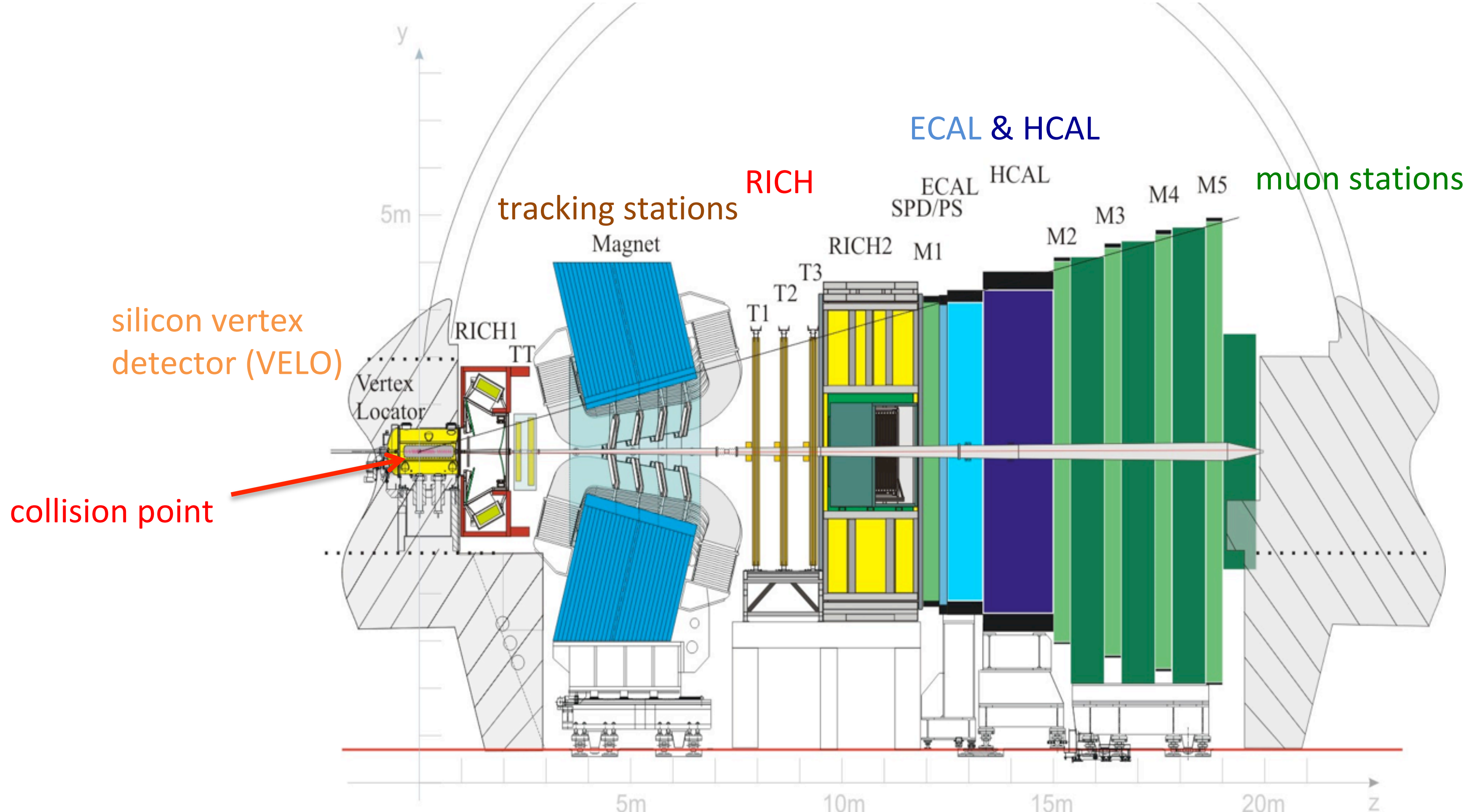
- Contributions from penguin ($b \rightarrow d$) and tree ($b \rightarrow u$) transitions.
- CPV expected from interference between tree and penguin diagrams.
- CPV expected from intermediate two-body resonant states.
  - → Not observed at B factories.

- CPT connection means possibility of “compound” CPV ($KK \leftrightarrow \pi\pi$ rescattering).

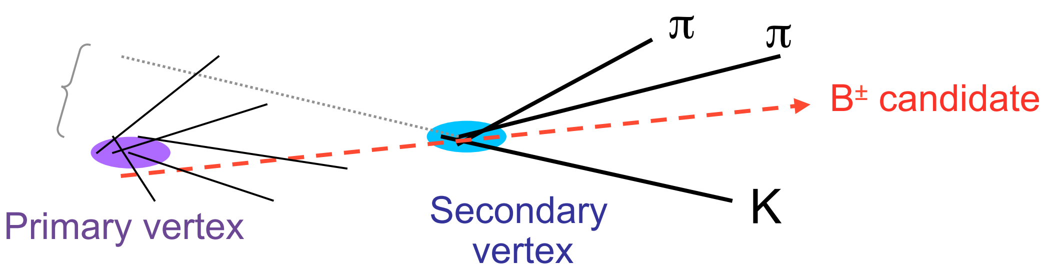
The LHCb experiment

Forward single-arm spectrometer, specialised in B and D decays.

- Acceptance $2 < \eta < 5$.



Analysis strategy



Measure direct CP asymmetry:

$$\mathcal{A}_{CP}^{\text{dir}} \equiv \frac{\Gamma(B \to f) - \Gamma(\bar{B} \to \bar{f})}{\Gamma(B \to f) + \Gamma(\bar{B} \to \bar{f})}$$

- Analysis of 3 fb^{-1} of Run-1 LHCb data: 2011 (7 TeV) and 2012 (8 TeV).
- Multivariate selection based on 3-body topology and displaced vertices.
- Particle identification (*K, π, p*) removes cross-feed contamination.
- Simultaneous invariant mass fit to B^+ and B^- samples: N_{signal}, A_{raw}.
- Raw asymmetries are corrected for variation of efficiency in phase space.
- Inclusive (time-integrated) CP asymmetry is obtained from raw asymmetry:

$$A_{CP}(hhh) = A_{raw}(hhh) - (A_D^{K/\pi} + A_{Prod}) = A_{raw}(hhh) - \Delta A$$

$K^\pm/\pi^\pm$ detection asymmetry — $B^\pm$ production asymmetry

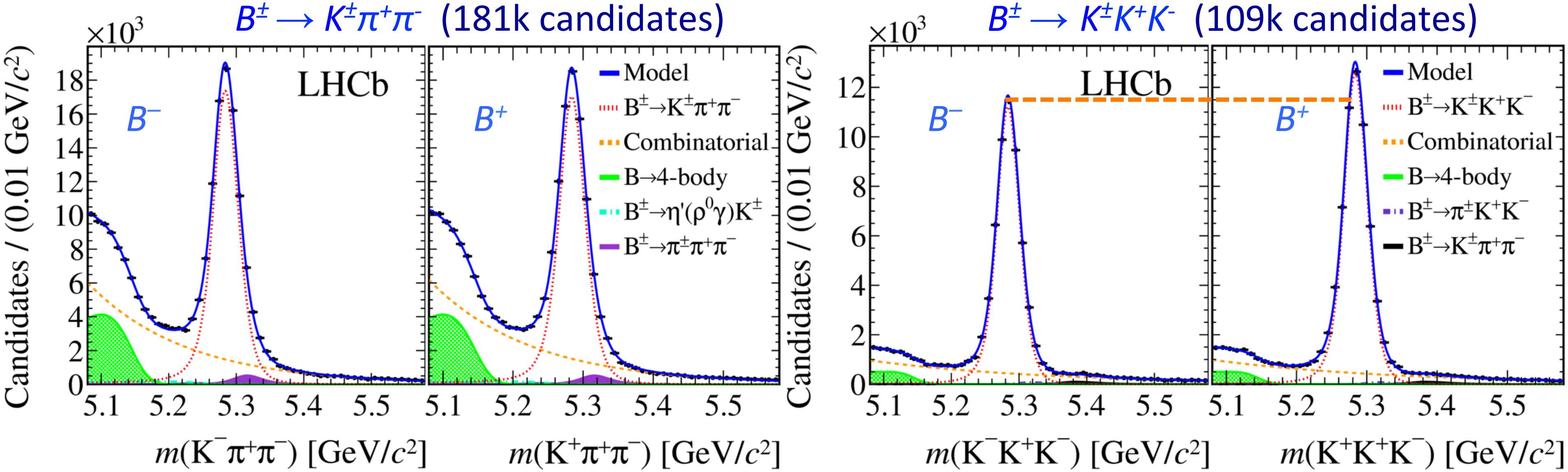
- The correction factor is measured from $B^\pm \to J/\psi\, K^\pm$ decays:

$$\Delta A = A_{raw}(J/\psi K) - A_{CP}(J/\psi K)\,, \qquad A_{CP}(J/\psi K) = (0.001 \pm 0.007)$$

PDG

CPV in $B^{\pm} \longrightarrow \pi^{+}\pi^{-}K^{\pm}, K^{+}K^{-}K^{\pm}$

$B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ (181k candidates) $B^{\pm} \rightarrow K^{\pm}K^{+}K^{-}$ (109k candidates)



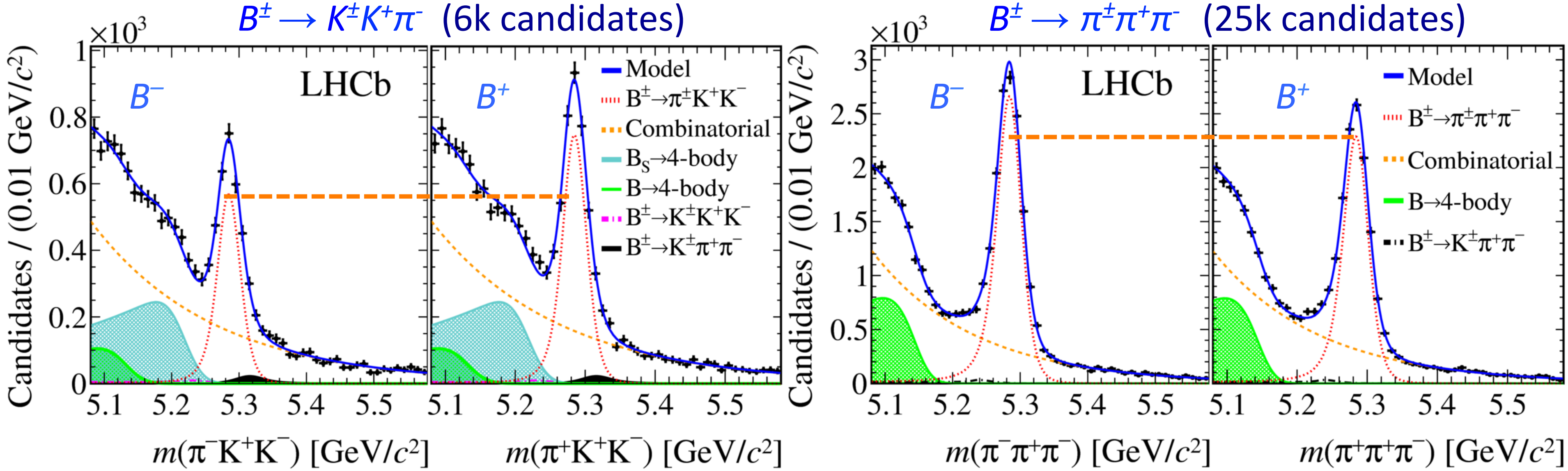
$$A_{CP}(B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}) = +0.025 \pm 0.004 \pm 0.004 \pm 0.007 \quad (2.8\sigma)$$
$$A_{CP}(B^{\pm} \rightarrow K^{\pm}K^{+}K^{-}) = -0.036 \pm 0.004 \pm 0.002 \pm 0.007 \quad (4.3\sigma)$$

- First evidence of inclusive CP asymmetry in three-body *B* decays.
- Asymmetries of opposite signs.

PRD 90 (2014) 112004,
PRL 111 (2013) 101801

CPV in $B^{\pm} \longrightarrow K^{+}K^{-}\pi^{\pm}, \pi^{+}\pi^{-}\pi^{\pm}$

$B^{\pm} \rightarrow K^{\pm}K^{+}\pi^{-}$ (6k candidates) $B^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ (25k candidates)



$$A_{CP}(B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}) = +0.058 \pm 0.008 \pm 0.009 \pm 0.007$$ (4.2σ)

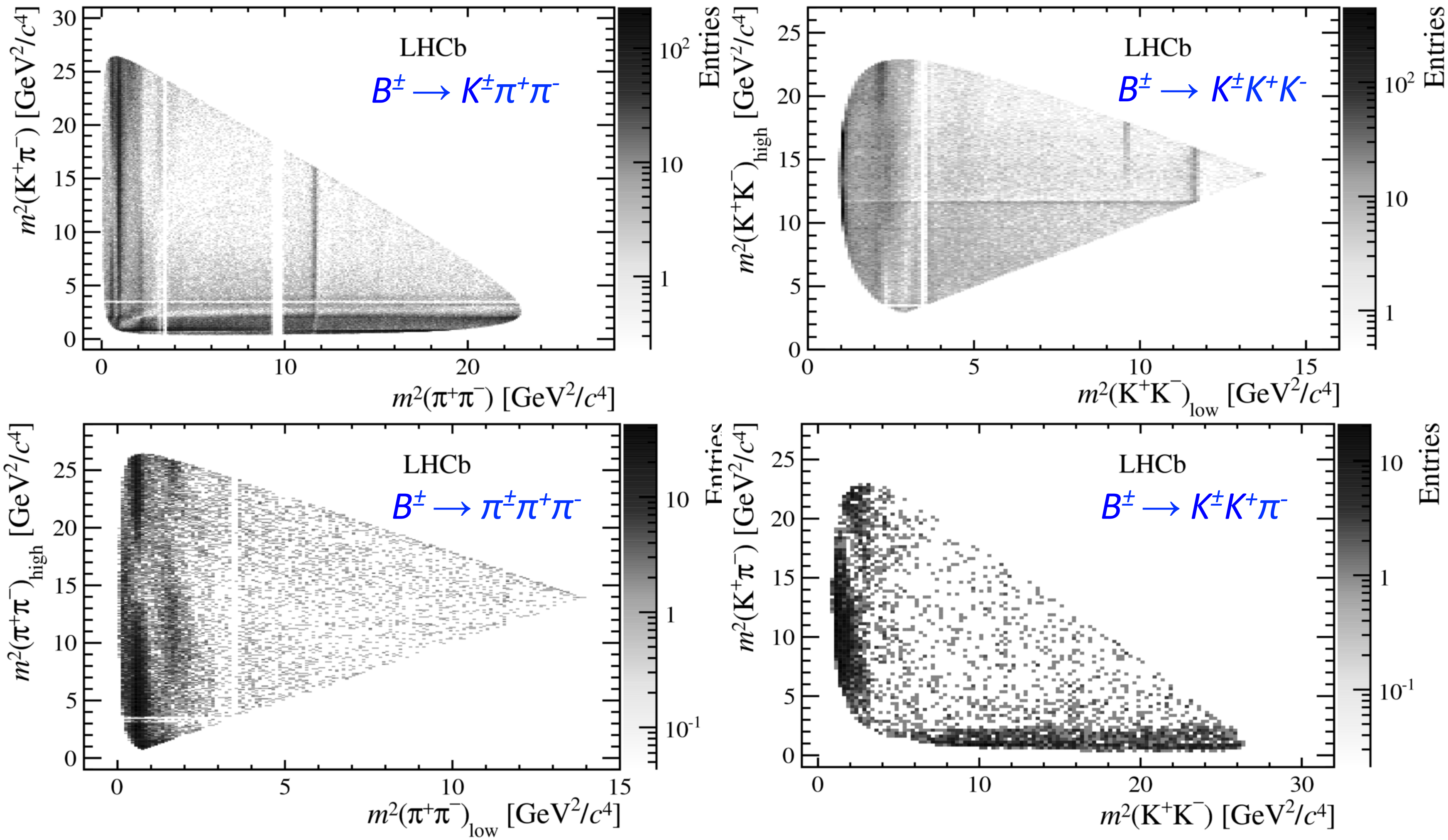
$$A_{CP}(B^{\pm} \to \pi^{\pm}K^{+}K^{-}) = -0.123 \pm 0.017 \pm 0.012 \pm 0.007$$ (5.6σ)

- First evidence of inclusive CP asymmetry in these decay channels.
- Asymmetries of opposite signs.

PRD 90 (2014) 112004,
PRL 112 (2013) 0111801

Phase space distributions

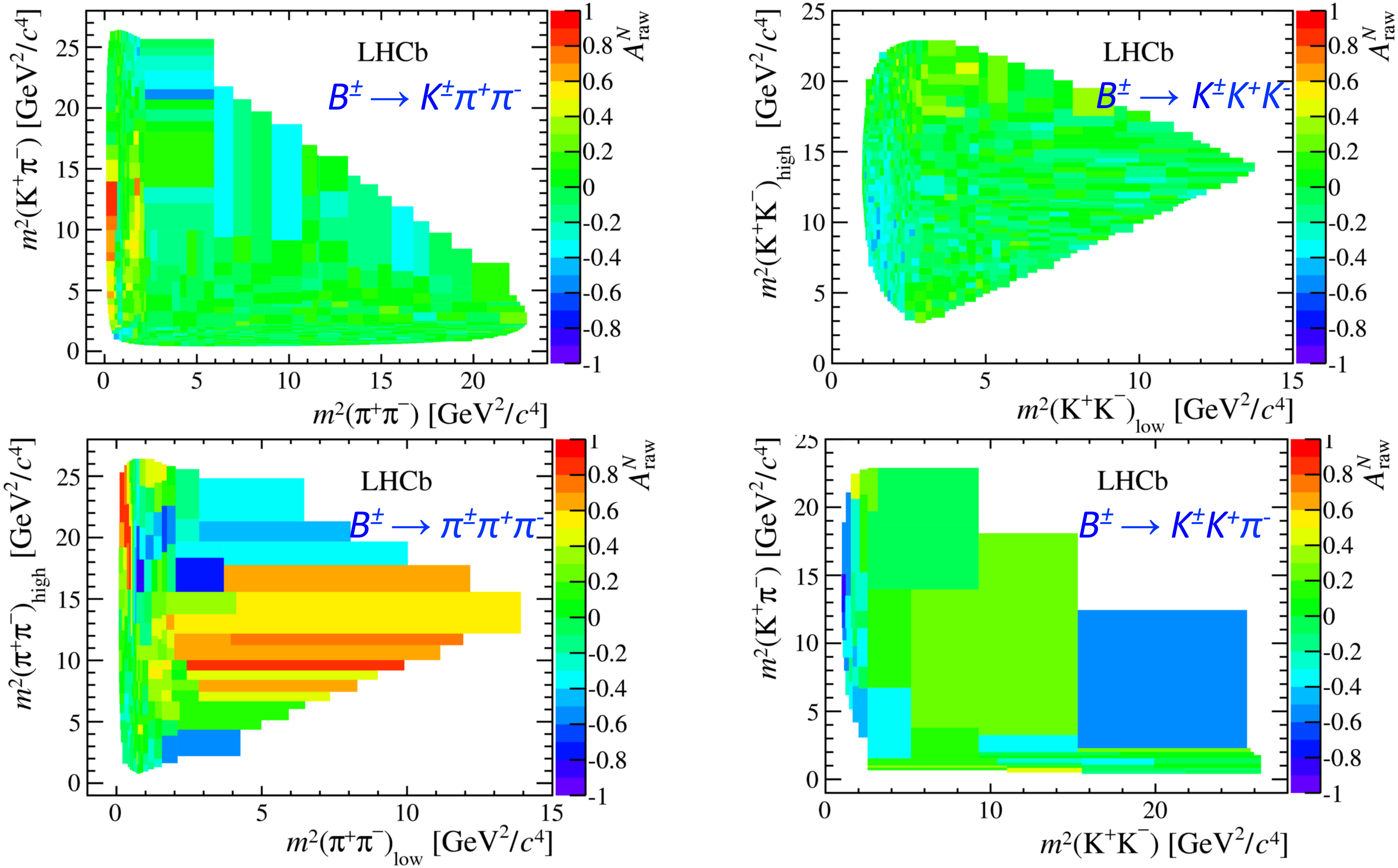
PRD 90 (2014) 112004



- Rich resonant structure at low *KK, Kπ* and *ππ* mass.

Local asymmetries

PRD 90 (2014) 112004

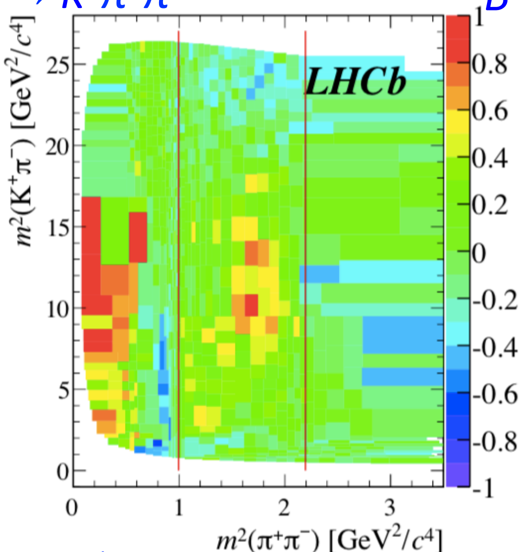


- Negative asymmetries at low *KK* mass and positive at low *ππ* mass.

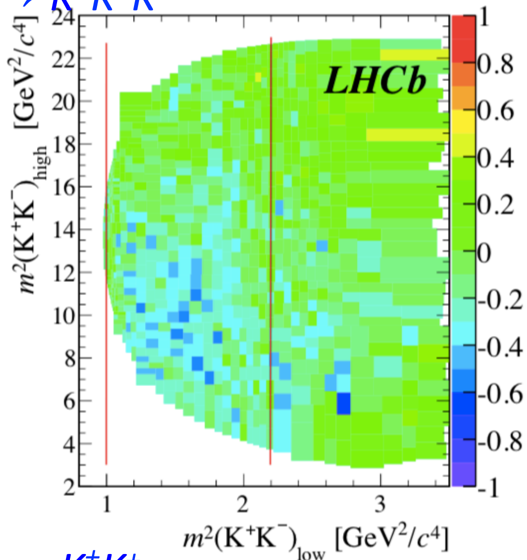
Local asymmetries

PRD 90 (2014) 112004

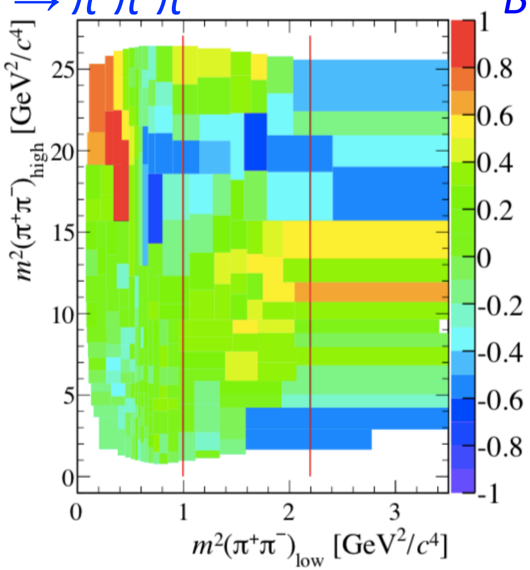
$B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$



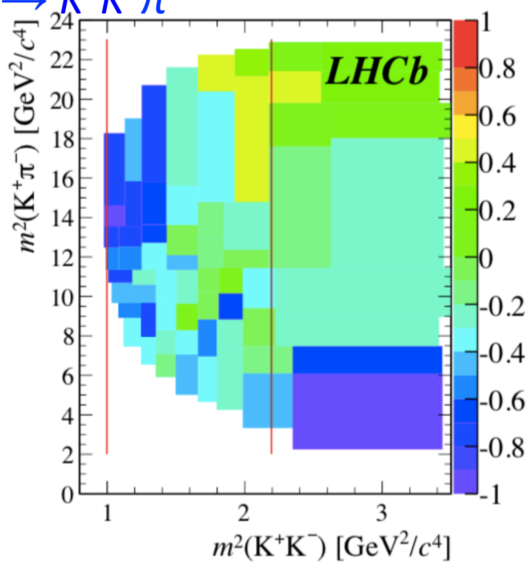
$B^{\pm} \to K^{\pm}K^{+}K^{-}$



$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$



$B^{\pm} \to K^{\pm}K^{+}\pi^{-}$



- Zoom at low *hh* mass in the (1.0, 2.2) GeV region.
- Negative for m_{KK} and positive at low $m_{\pi\pi}$.
- Could indicate $KK \leftrightarrow \pi\pi$ rescattering.

Decay	A_{CP}
$B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$	$+0.121 \pm 0.022$
$B^{\pm} \to K^{\pm}K^{+}K^{-}$	-0.211 ± 0.014
$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$	$+0.172 \pm 0.027$
$B^{\pm} \to \pi^{\pm}K^{+}K^{-}$	-0.328 ± 0.041

Amplitude analyses

Preliminary
LHCb Unofficial

- Amplitude analyses are underway to quantify the sources of CP violation and the underlying dynamics.
- Isobar model: the amplitude at each point in phase space is a coherent sum of individual resonant (R) and non-resonant amplitudes.

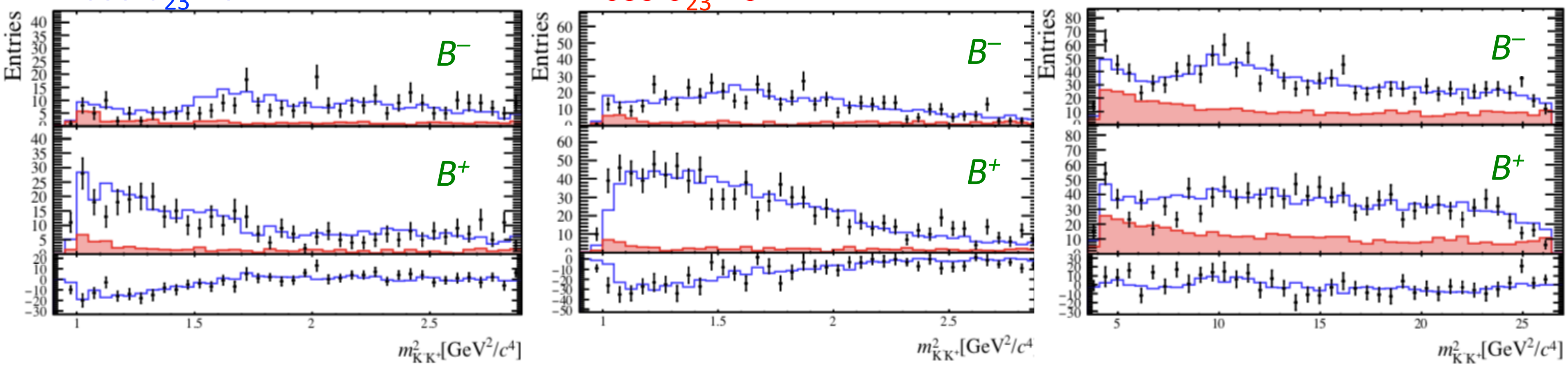
$$\mathcal{A}(m_{13}, m_{23}) = \sum_{i=1}^{N} c_i \mathcal{M}_{Ri}(m_{13}, m_{23})$$

$$c_i = (x_i + \Delta x_i) + i(y_i + \Delta y_i)$$
$$\overline{c_i} = (x_i - \Delta x_i) + i(y_i - \Delta y_i)$$

- Complex coefficients c_j of each component contain weak phase dependence (Δx, Δy quantify CPV).
- The resonant amplitude $\mathcal{M}_R$ contains the strong phase dependence, angular terms and barrier factors.

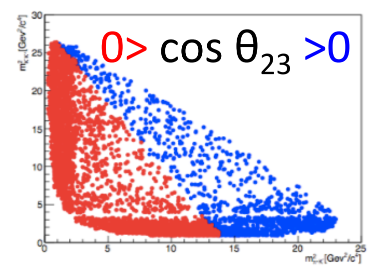
$B^{\pm} \to K^{+}K^{-}\pi^{\pm}$ amplitude analysis

Preliminary
LHCb Unofficial



- Isobar model.
- Resonances in m_{KK}: $\rho^0(1450)$, $f_2(1270)$, $\phi(1020)$.
- Resonances in $m_{K\pi}$: $K^{*0}(892)$, $K^{*0}(1430)$, non-resonant (Tobias parametrisation).
- $KK \leftrightarrow \pi\pi$ rescattering contribution (Pelaez parametrisation) with large negative asymmetry.

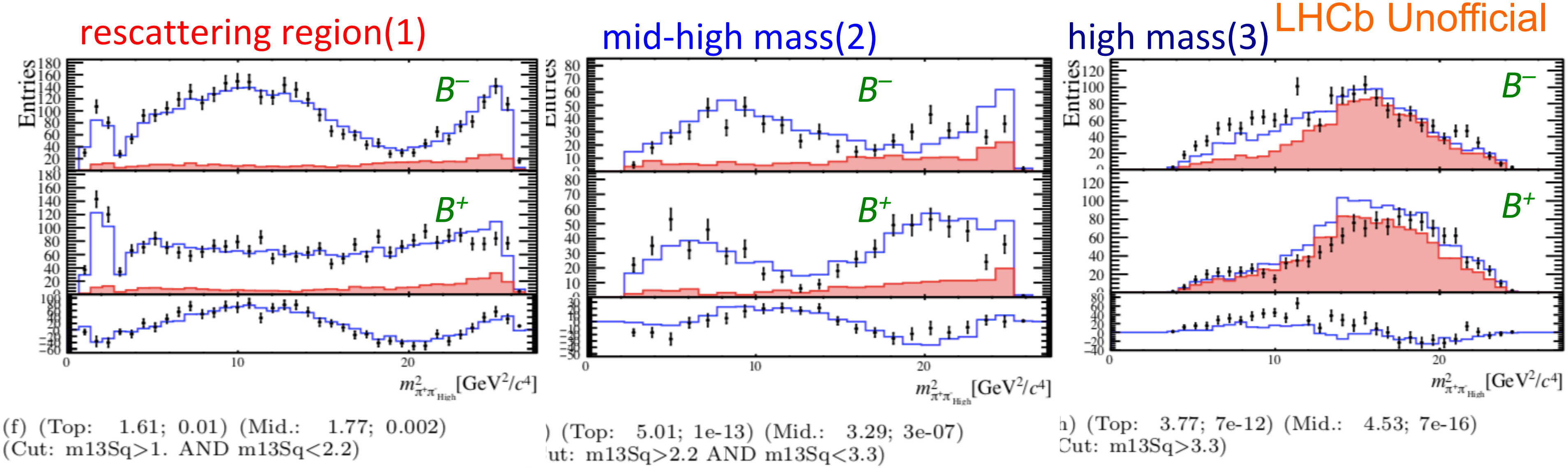
Bediaga et al,
PRD 92 (2010) 054010



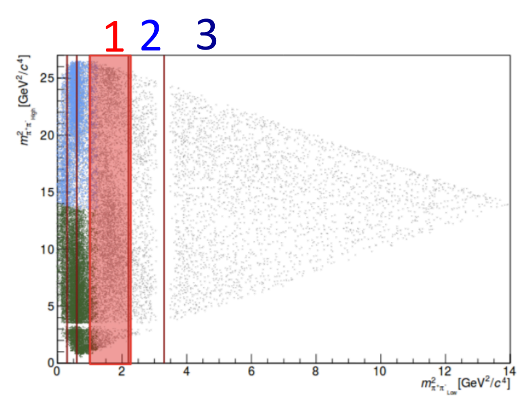
Pelaez et al,
PRD 71 (2005) 074016

$B^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm}$ amplitude analysis

Preliminary
LHCb Unofficial



- Isobar model, K-matrix and quasi-model-independent (QMI) analysis.
- S-wave parametrisation for σ + rescattering.
- Resonances in $m_{\pi\pi}$: $\rho^0(770) - \omega(782)$ mixing, $\rho_3(1690)$ $f_2(1270)$, $\rho^0(1450)$.
- $KK \leftrightarrow \pi\pi$ rescattering with large positive asymmetry.



Conclusions

- Three-body charmless $B^{\pm}$ decays are an excellent laboratory for studying direct CP violation.
  - Inclusive CP asymmetries are well established.
  - Rich pattern of large, localised asymmetries in phase space.
  - May be due to different sources of CPV: resonances, interference, final-state interactions.

- Full Dalitz plot amplitude analyses are underway for the four channels.
- Update with Run-2 data will increase our precision.