CP violation measurements in three-body charmless B decays

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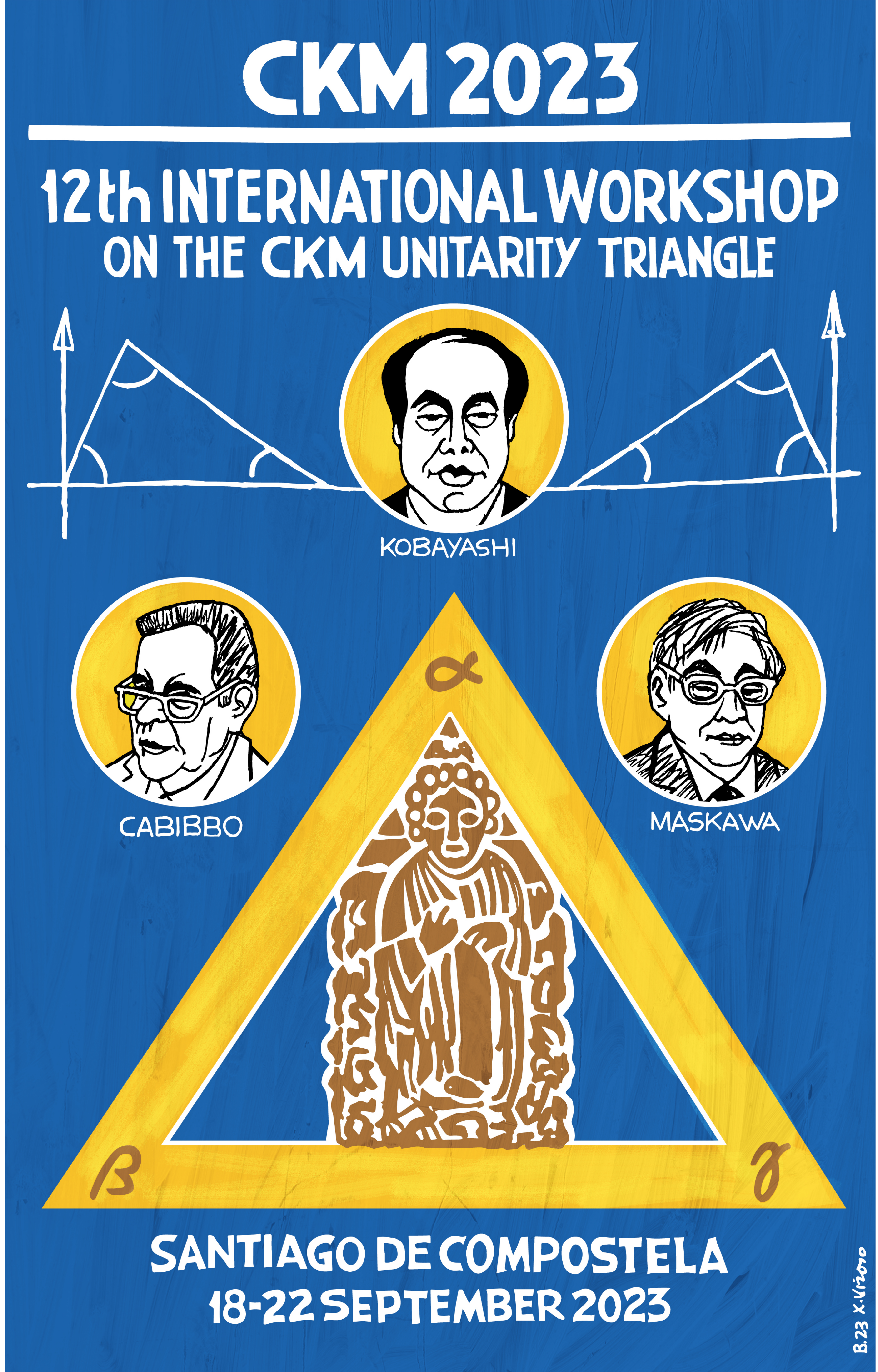
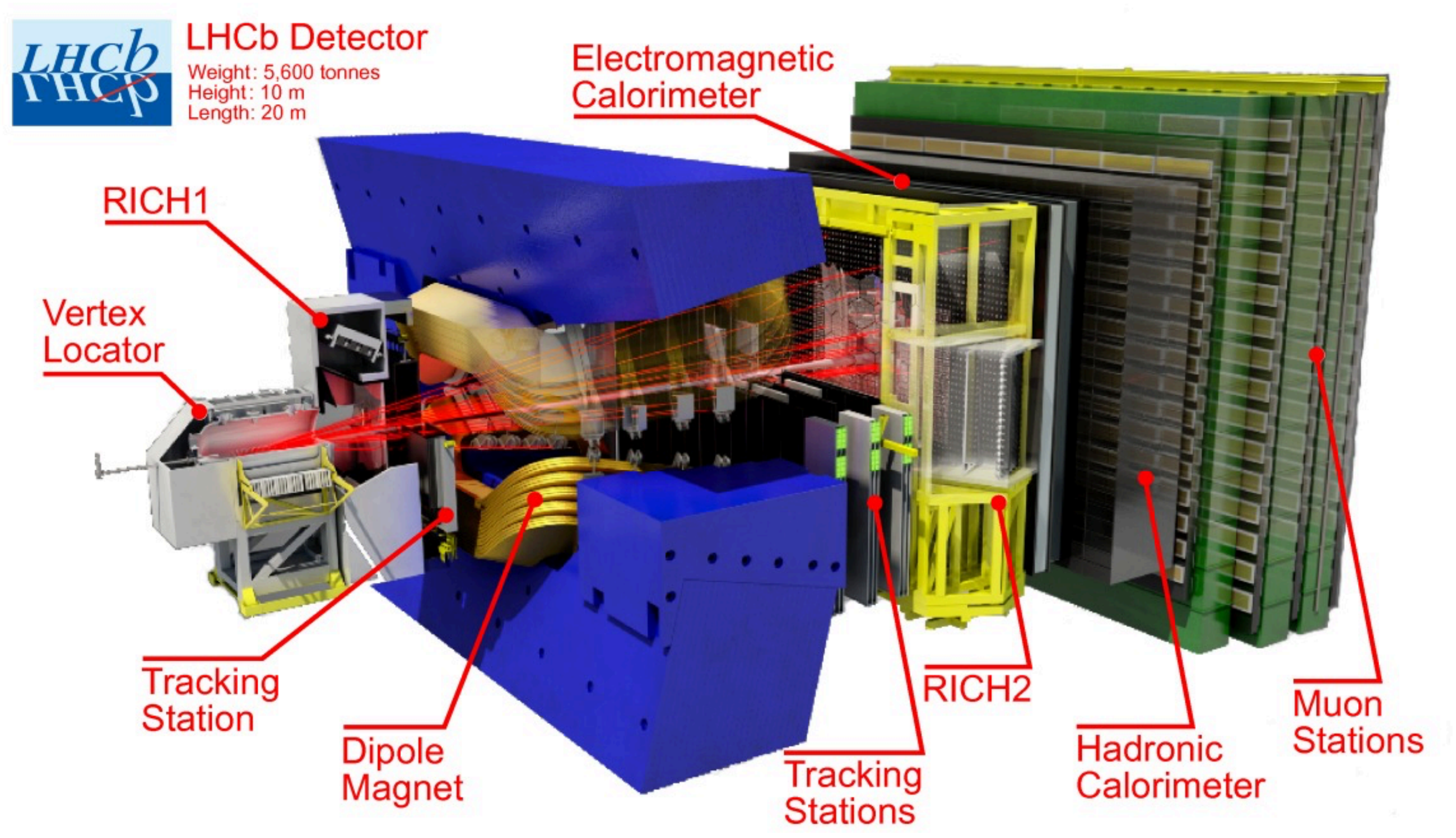
on behalf of the LHCb Collaboration

LHCb

CBPF



- LHCb detector:
  - Single-arm spectrometer with high-precision of tracking, particle identification and decay vertex system
- Presentation based on RUN II data of LHCb:
  - $\mathscr{L} = 5.9\ fb^{-1}$ using $p-p$ collisions and centre-of-mass energy of $13\ TeV$ (2015 - 2018)



- Papers to be presented:
  - Direct CP violation in charmless three-body decays of $B^{\pm}$ mesons PRD.108.012008(2023)
  - Search for direct CP violation in charged charmless $B \to PV$ decays PRD.108.012013(2023)

Introduction

- The Analysis is motivated by significant asymmetries observed in $B^{\pm} \to h^{\pm}h^{+}h^{-} (h = K, \pi)$ during the RUN I
  - Measurements of CP violation in three-body phase space of charmless $B^{\pm}$ decays PhysRevD.90.112004
  - Amplitude analysis of $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \to \pi^{\pm}K^{+}K^{-}$ decays

PhysRevLett.124.031801(2020)

PhysRevLett.123.231802(2019)

PhysRevD101012006(2020)

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

→

- $B^{\pm} \to (V \to h^{+}h^{-})h^{\pm}$ contributions:
  - $B^{\pm} \to (\rho(770)^{0} \to \pi^{+}\pi^{-})\ \pi^{\pm}$
  - $B^{\pm} \to (\rho(770)^{0} \to \pi^{+}\pi^{-})\ K^{\pm}$
  - $B^{\pm} \to (K^{*}(892)^{0} \to K^{+}\pi^{-})\ \pi^{\pm}$
  - $B^{\pm} \to (K^{*}(892)^{0} \to K^{+}\pi^{-})\ K^{\pm}$
  - $B^{\pm} \to (\phi(1020) \to K^{+}K^{-})\ K^{\pm}$

- Technical elements
  - Selection based on Multivariate, PID and charm vetoes
  - Efficiency obtained from Monte Carlo simulation samples

Theory Overview

- Direct CPV arises from the interference between amplitudes with ***different*** weak and strong phases leading to the same final state:

  - ☑ Strong phase: short-distance penguin contributions, hadronic final-state-interactions(FSI)
  - ☑ Weak phase: CKM matrix elements

- Example of at least 2 competitive amplitudes:

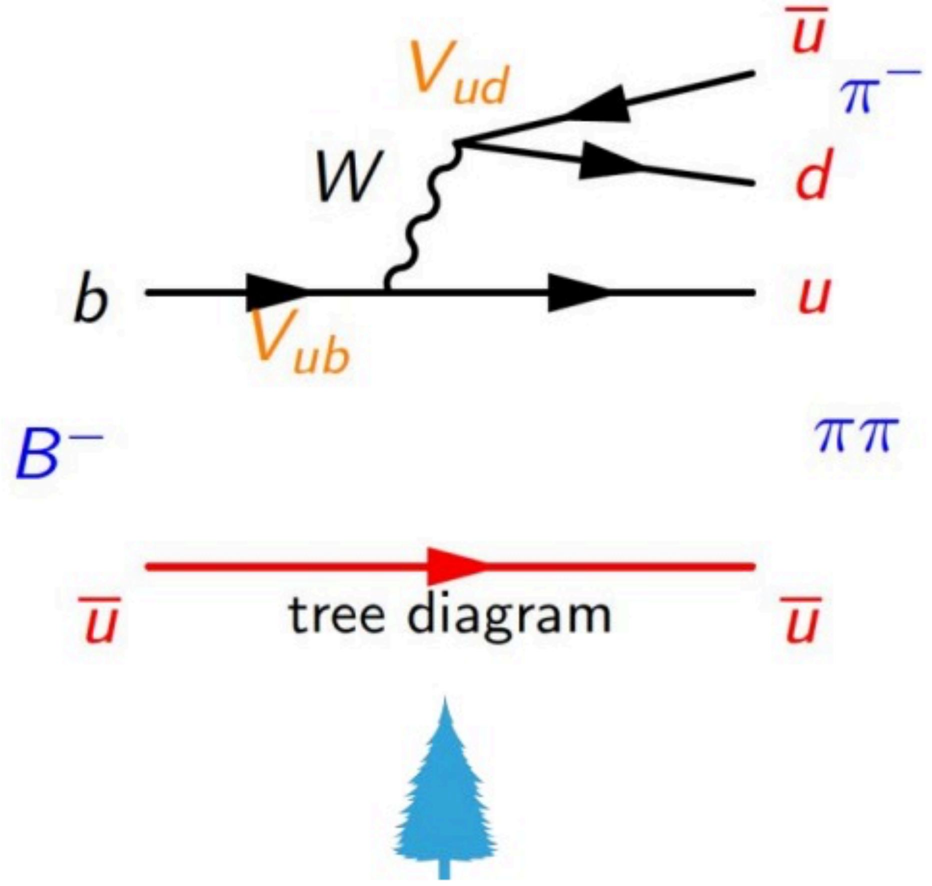
$$A(B \to f) = |A_1| e^{i(\delta_1 + \gamma_1)} + |A_2| e^{i(\delta_2 + \gamma_2)}$$

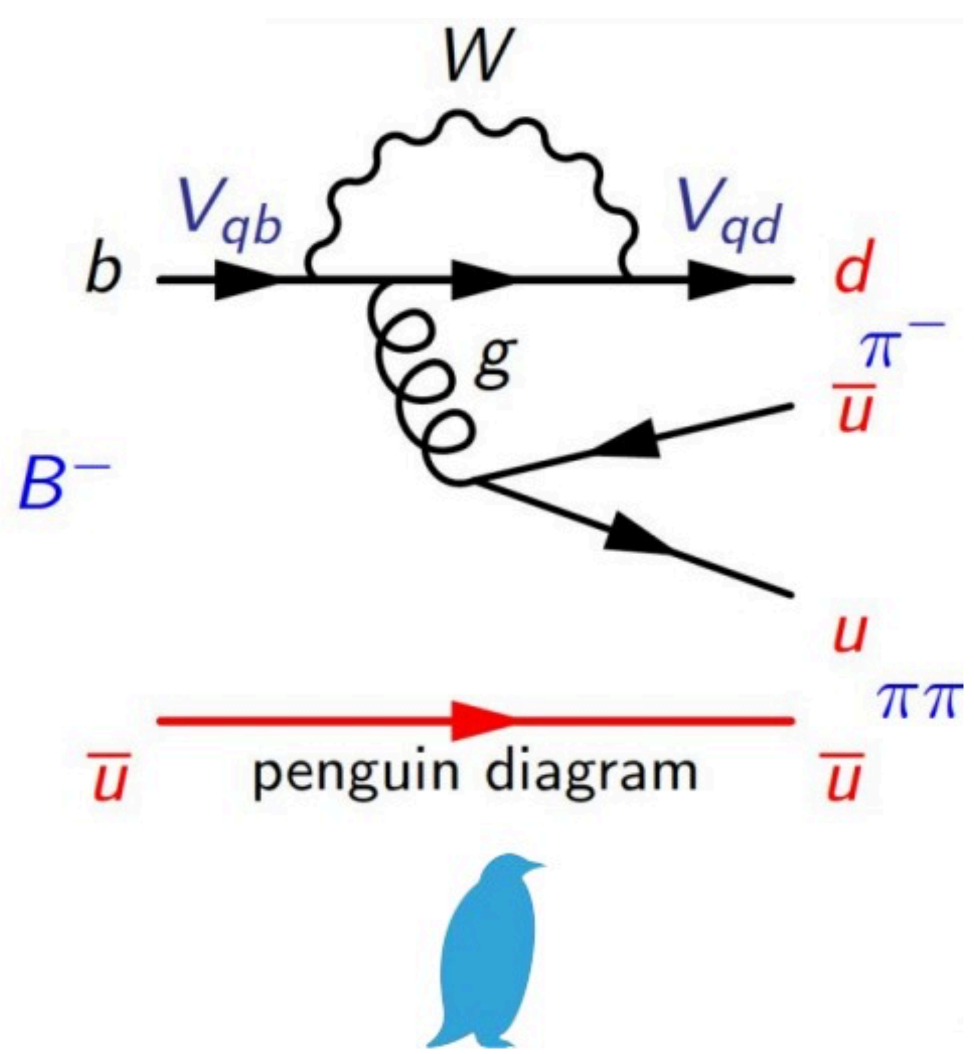
$$A(\bar{B} \to \bar{f}) = |A_1| e^{i(\delta_1 - \gamma_1)} + |A_2| e^{i(\delta_2 - \gamma_2)}$$

$$A_{CP} = \frac{|A(B \to f)|^2 - |A(\bar{B} \to \bar{f})|^2}{|A(B \to f)|^2 + |A(\bar{B} \to \bar{f})|^2}$$

$$= \frac{2|A_2/A_1| sin(\delta_1 - \delta_2)\, sin(\gamma_1 - \gamma_2)}{1 + |A_2/A_1|^2| + |A_2/A_1| cos\,(\delta_1 - \delta_2)\, cos\,(\gamma_1 - \gamma_2)}$$

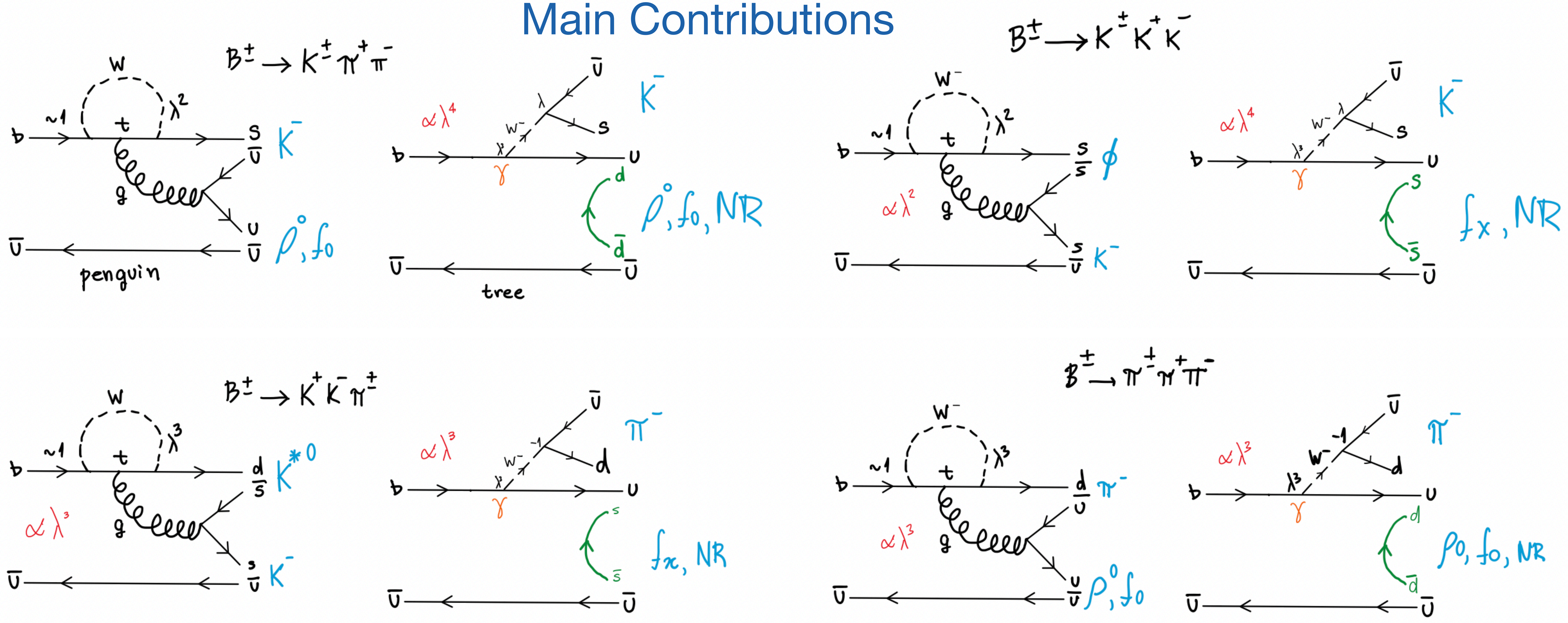
Example: $B^- \to \pi^-\pi^+\pi^-$ decay





Theory Overview

Main Contributions



- CPV coming from the interferences between: PhysRevD.92.054010
  - ☑ Penguin and Tree diagrams
  - ☑ Resonances in the phase space
  - ☑ Different final states coupled by the FSI: CPT constraint → *Rescattering* $\pi\pi \leftrightarrow KK$

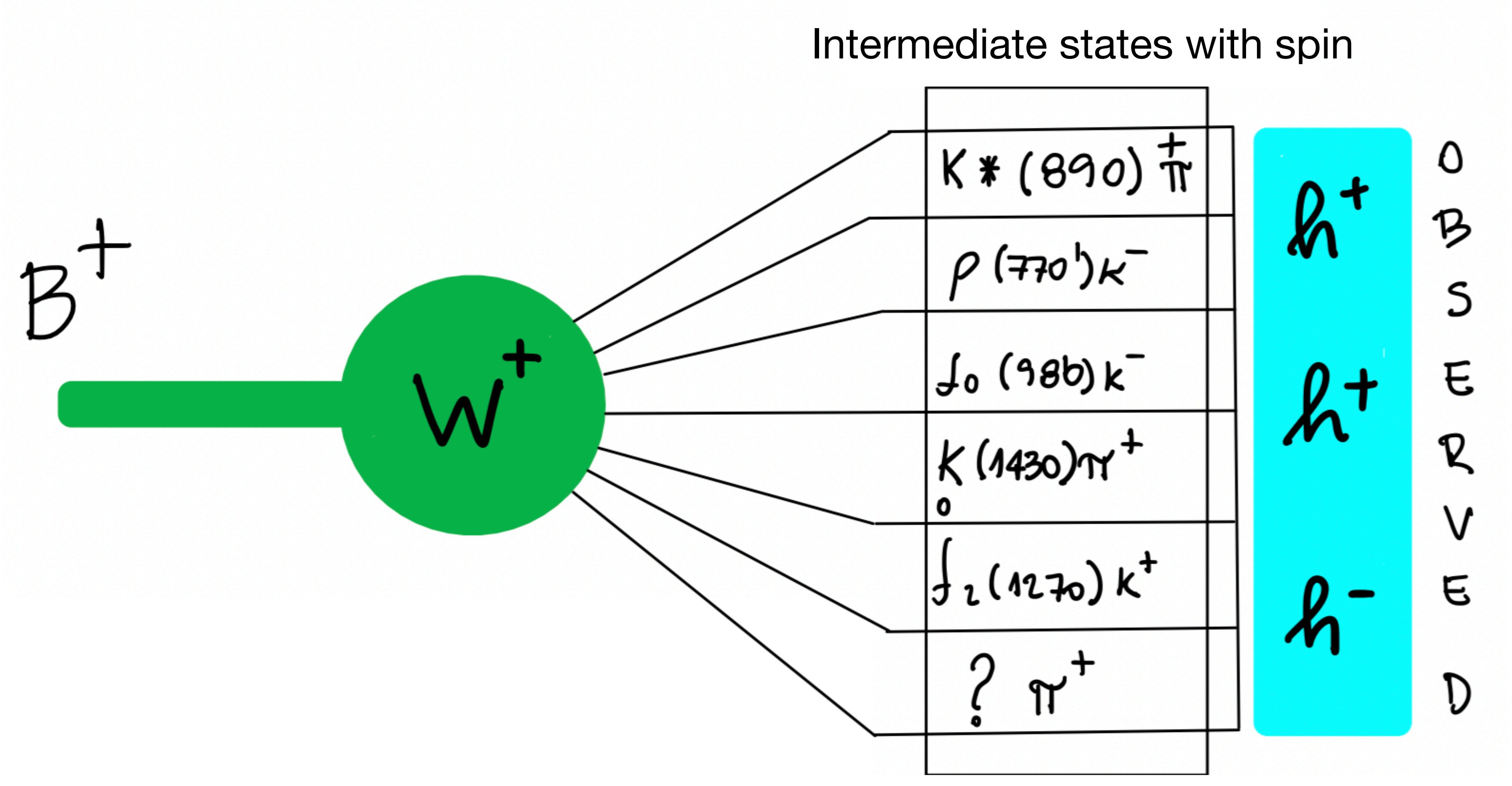
Hadronic Rescattering

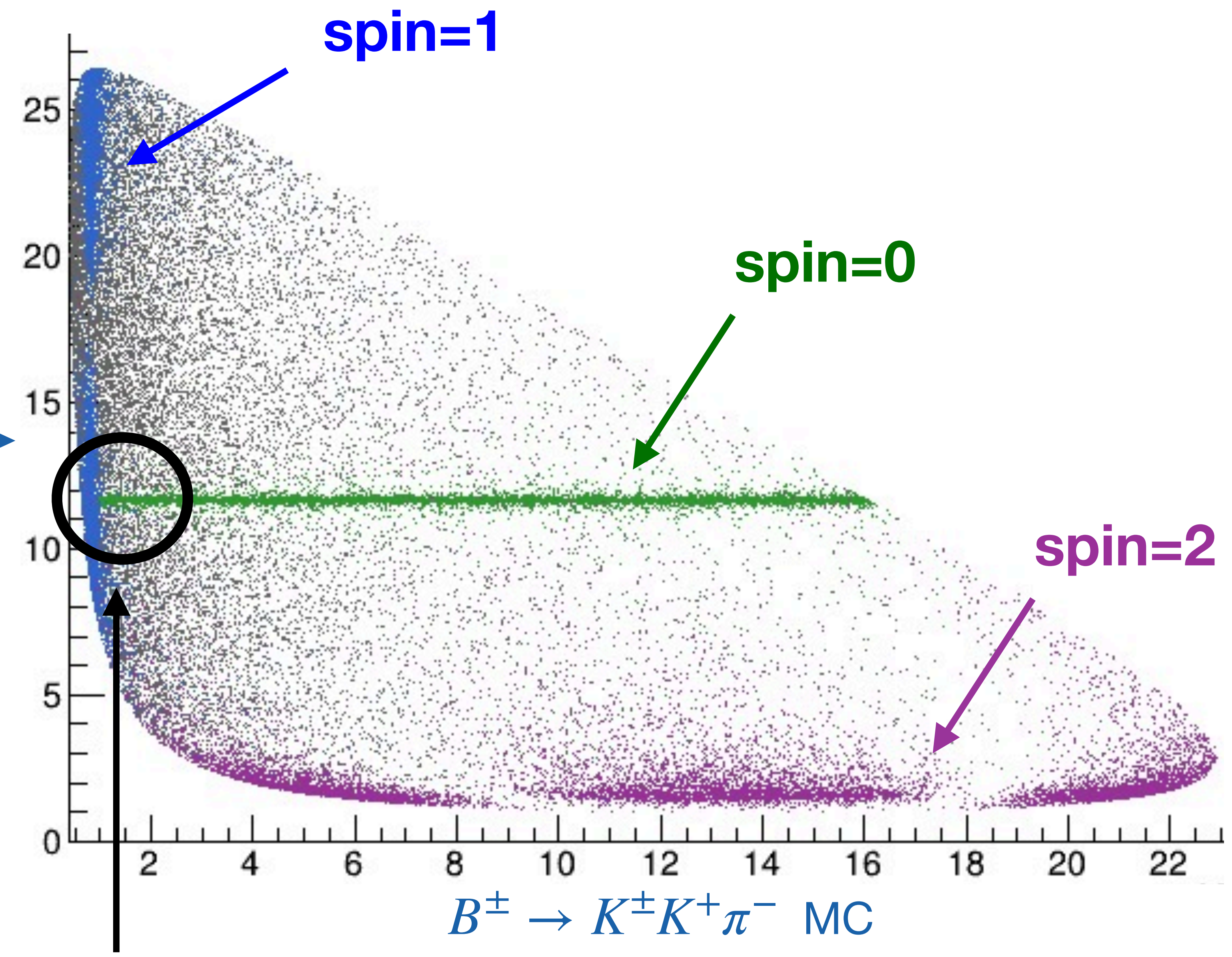
- CPT constraints on CP Violation
  - CP violation: $\Gamma(P \to f) - \Gamma(\bar{P} - \bar{f}) \neq 0$
  - CPT symmetry: total decay widths of P and $\bar{P}$ are the same

$$\Gamma(P \to f_1) + \ldots + \Gamma(P \to f_n) = \Gamma(\bar{P} \to \bar{f}_1) + \ldots + \Gamma(\bar{P} \to \bar{f}_n)$$

- “Communication” between the different decay modes with the same flavor quantum numbers
  - Ex: $B^\pm \to \pi^\pm K^+ K^-$ and $B^\pm \to \pi^\pm \pi^+ \pi^-$
  - CPV with opposite signs in partner channels
- Final-state-interactions:
  - Provides the strong phases for CP violation to be observed
  - It is a key ingredient to preserve CPT symmetry

$B^{\pm} \to h^{\pm}h^{+}h^{-}$ — The Dalitz Plot





Overlap between vector and scalar resonances

- Two degrees of freedom
- Phase-space graphical representation of the spinless decay
- $$d\Gamma = \frac{1}{(2\pi)^3}\frac{1}{32M^3}|\mathcal{M}|^2 \mathrm{d}m_{ij}^2\,\mathrm{d}m_{jk}^2$$

The total decay amplitude squared holds information regarding the dynamics

- Why is three-body decays particularly interesting?
  - ☑ All final states have rich resonant structure
  - ☑ Additional source of strong phase difference
  - ☑ Large effects in regions of the Dalitz Plot may arise

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

$B^\pm \to h^\pm h^+ h^-$ — Mass fit results

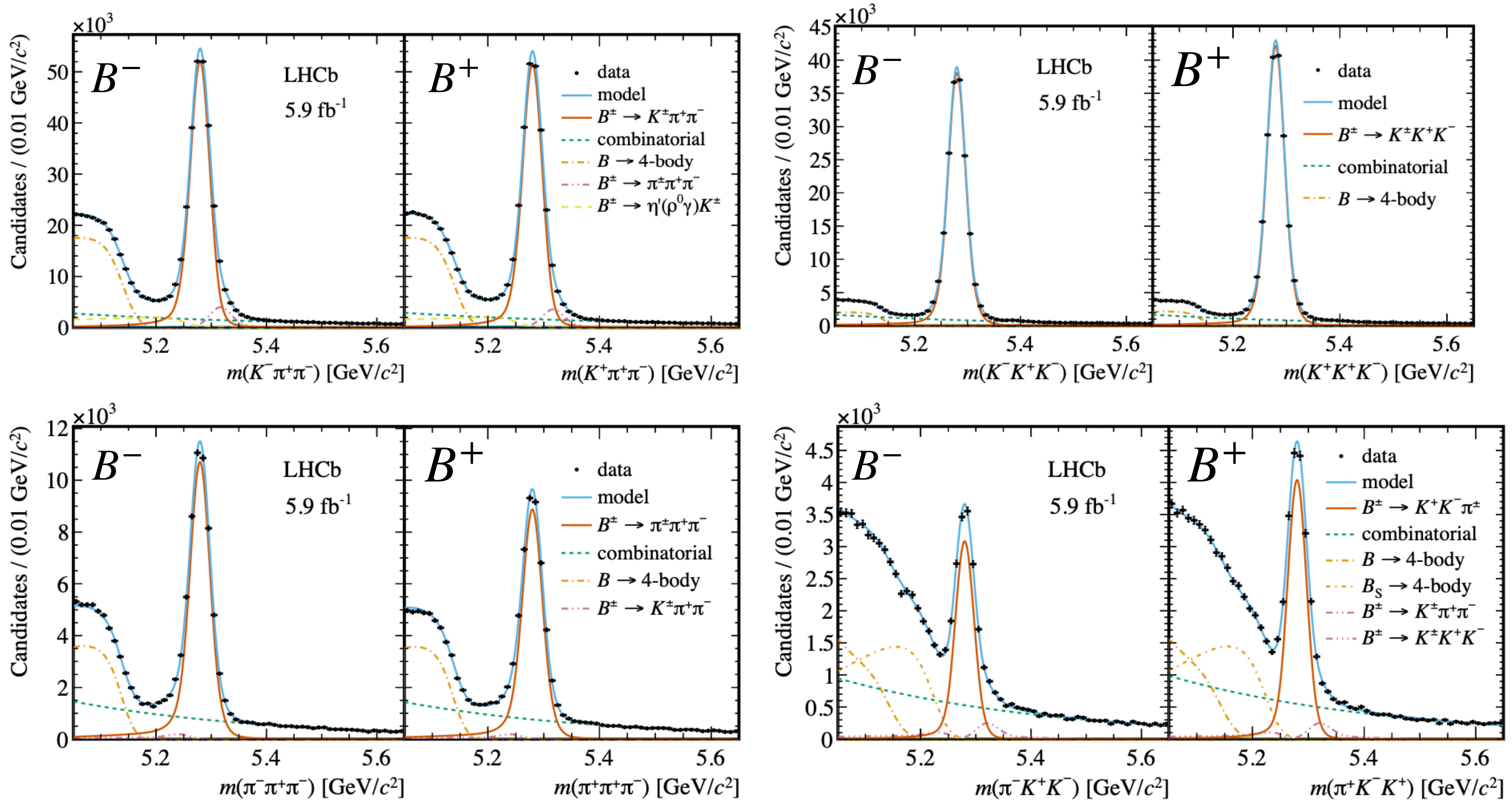
Invariant mass fit

- Signal PDF:
  - ☑ Gaussian + two Crystal Balls functions
- Background:
  - ☑ Combinatorial: exponential function
  - ☑ Partially reconstructed background: Argus function convolved with a Gaussian
  - ☑ Peaking from other $B \to hhh$ decays: Two Crystal Balls functions

Fit observables

- *Signal yield*
- *Raw asymmetry*

$$A_{raw} = \frac{N^- - N^+}{N^- + N^+}$$



Decay mode	Total yield	$A_{\rm raw}$
$B^\pm \to K^\pm\pi^+\pi^-$	$499\,200 \pm 900$	$+0.006 \pm 0.002$
$B^\pm \to K^\pm K^+ K^-$	$365\,000 \pm 1000$	-0.052 ± 0.002
$B^\pm \to \pi^\pm\pi^+\pi^-$	$101\,000 \pm 500$	$+0.090 \pm 0.004$
$B^\pm \to \pi^\pm K^+ K^-$	$32\,470 \pm 300$	-0.132 ± 0.007

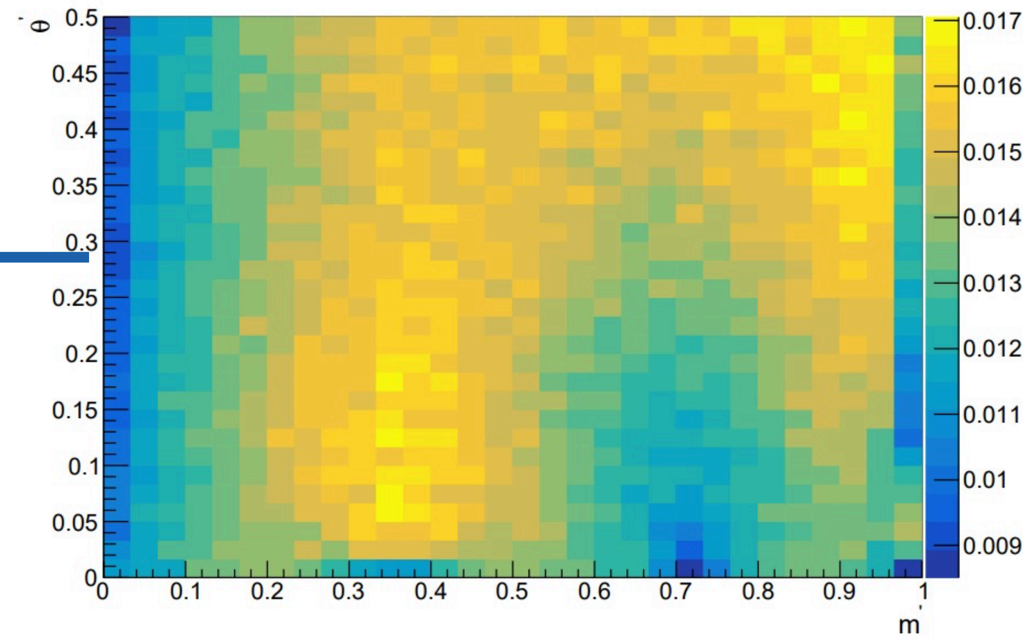
CP asymmetry

- The efficiency-corrected raw asymmetry:

$$< \epsilon^{\pm} >= \frac{\sum_{i'=1}^{events'} 1}{\sum_{i'=1}^{events'} \frac{1}{acc'_i}}$$

$$R = \frac{< \epsilon^{-} >}{< \epsilon^{+} >}$$

$B^{\pm} \to K^{\pm}K^{+}K^{-}$ ACC obtained through MC



- acc'_i: acceptance for the event i
- $\epsilon^{\pm}$: efficiency weights
- R: efficiency correction factor
- A_{raw}^{corr}: efficiency-corrected raw asymmetries

$$A_{raw}^{corr} = \frac{1 + A_{RAW} - R + A_{RAW} \cdot R}{1 + A_{RAW} + R - A_{RAW} \cdot R}$$

- The production asymmetry

$$A_P = A(B^{\pm} \to J/\psi K^{\pm})_{data} - A(B^{\pm} \to J/\psi K^{\pm})_{PDG}$$

Used as control channel once CPV is not expected to appear

- The physical CP asymmetry:

$$A_{CP} = \frac{A_{raw}^{corr} - A_P}{1 - A_{raw}^{corr} A_P}$$

Phase space integrated asymmetries

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

$$A_{CP} = (+1.1 \pm 0.2_{stat} \pm 0.3_{syst} \pm 0.3_{J/\psi K})\,\%$$ ⟵ 2.4σ

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

$$A_{CP} = (-3.7 \pm 0.2_{stat} \pm 0.2_{syst} \pm 0.3_{J/\psi K})\,\%$$ ⟵ 8.5σ

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

$$A_{CP} = (+8.0 \pm 0.4_{stat} \pm 0.3_{syst} \pm 0.3_{J/\psi K})\,\%$$ ⟵ 14.1σ

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

$$A_{CP} = (-11.4 \pm 0.7_{stat} \pm 0.3_{syst} \pm 0.3_{J/\psi K})\,\%$$ ⟵ 13.6σ

First observation of CPV in $B^{\pm} \to K^{\pm}K^{+}K^{-}$, $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$

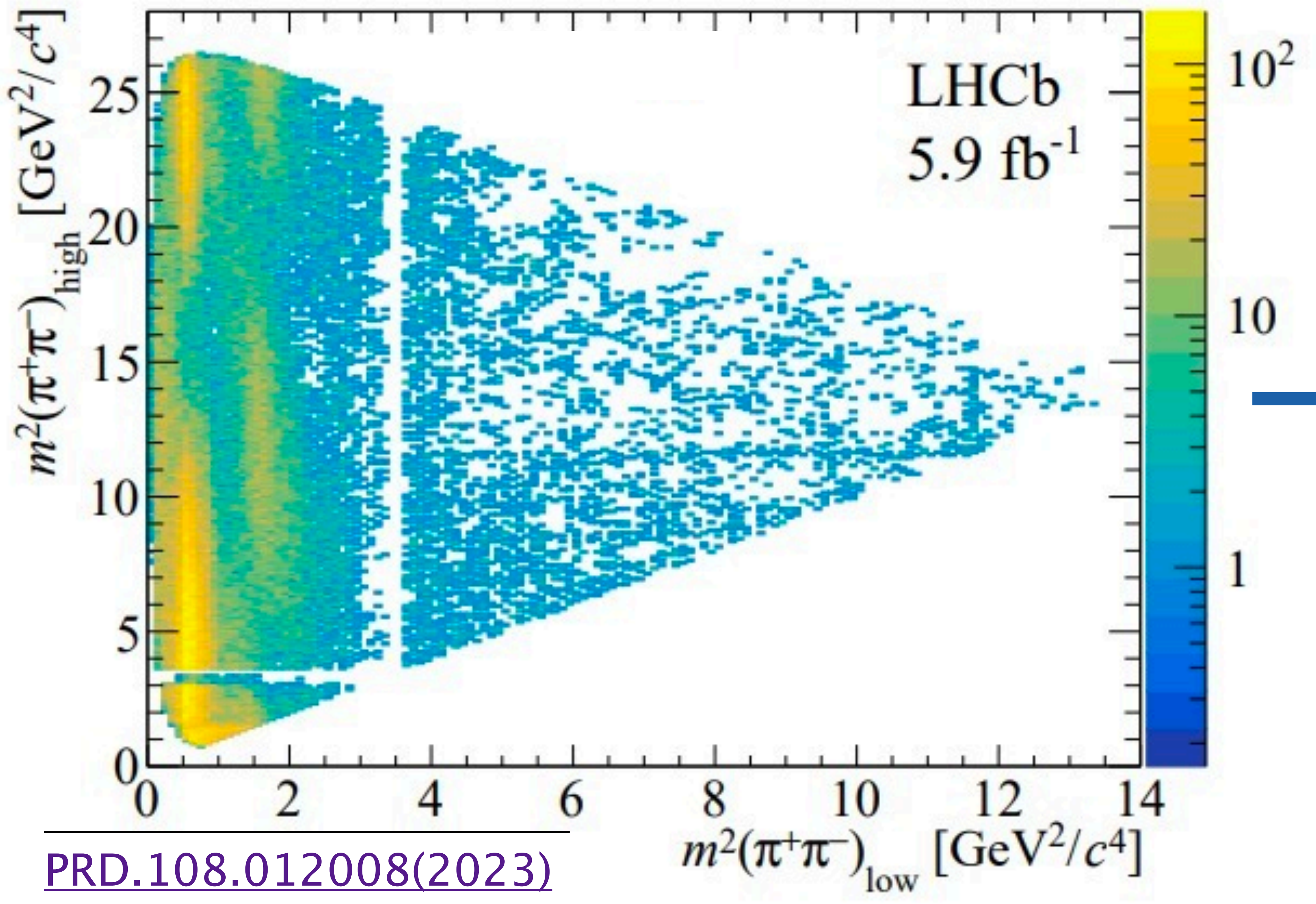
Run I results

$A_{CP}(B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = +0.025 \pm 0.004 \pm 0.004 \pm 0.007$ ⟵ 2.8σ

$A_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.036 \pm 0.004 \pm 0.002 \pm 0.007$ ⟵ 4.3σ

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

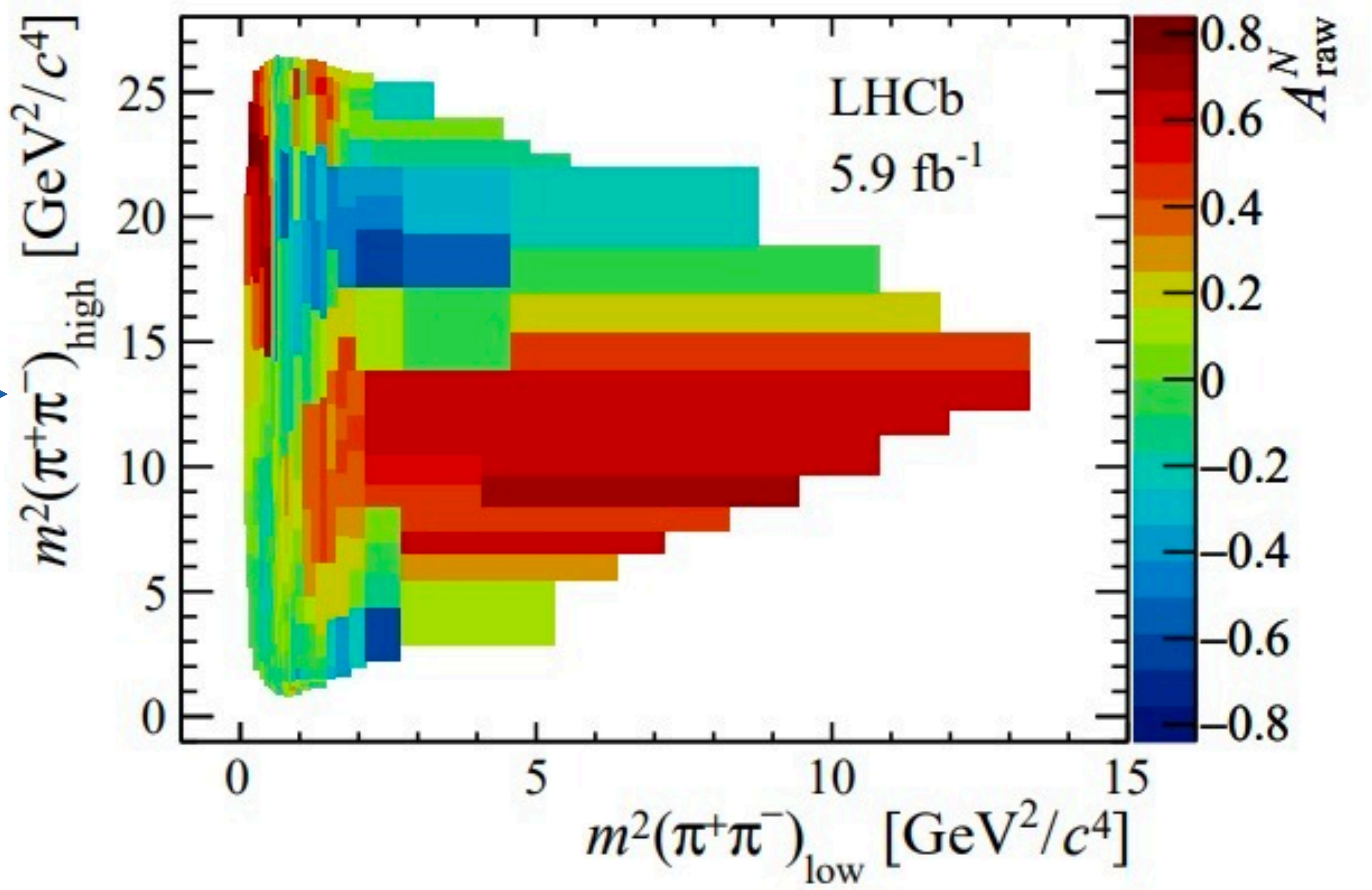
$A_{CP}(B^{\pm} \to \pi^{\pm}K^{+}K^{-}) = -0.123 \pm 0.017 \pm 0.012 \pm 0.007$ ⟵ 5.6σ



PRD.108.012008(2023)

$$A_{CP}^{bin} = \frac{N^- - N^+}{N^- + N^+}$$

Miranda method

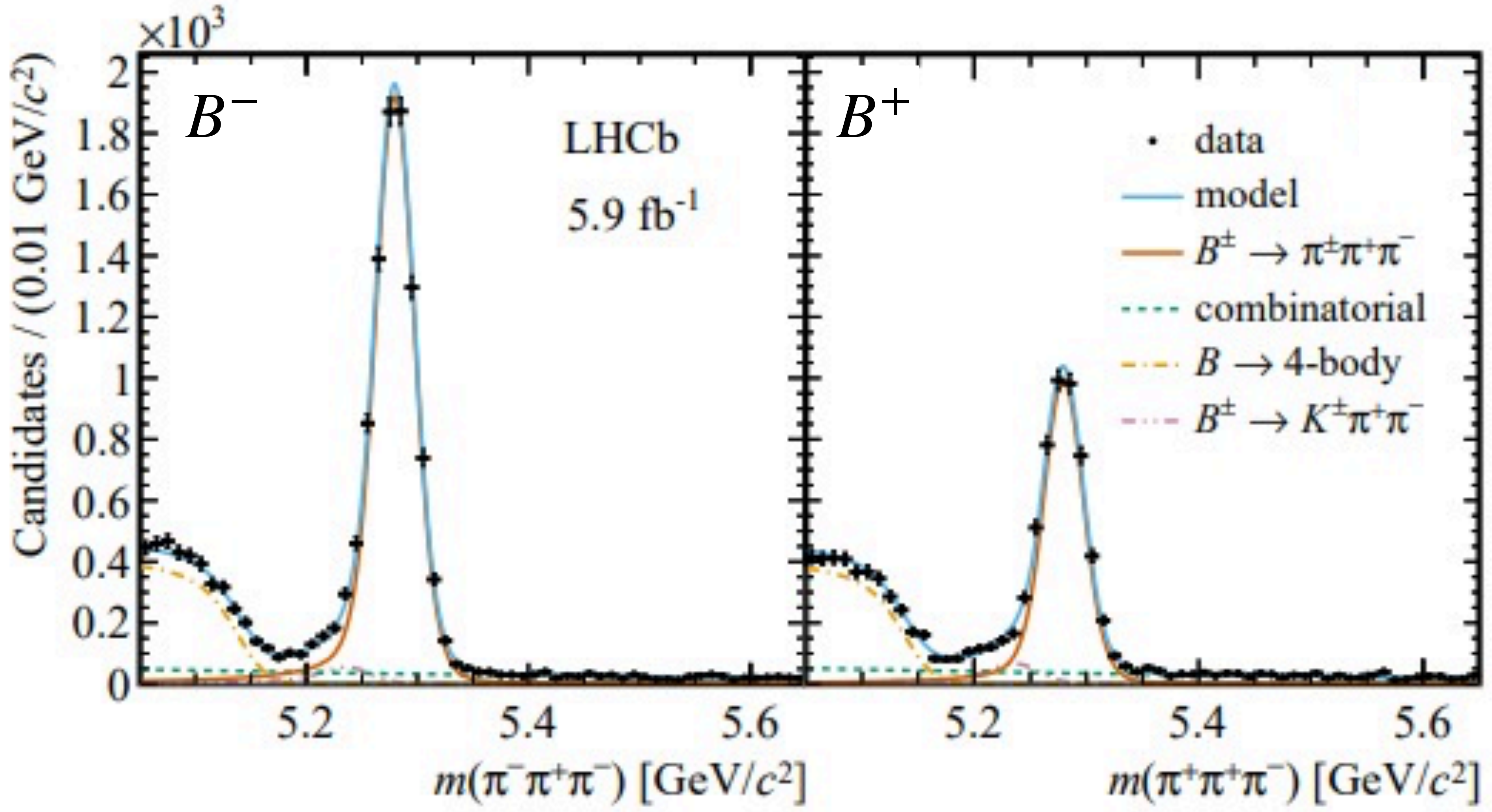


- Histogram created by an adaptive binning algorithm
- The asymmetry is calculated from the number of events in the bin
- Localized asymmetry within the range -80% — +80%

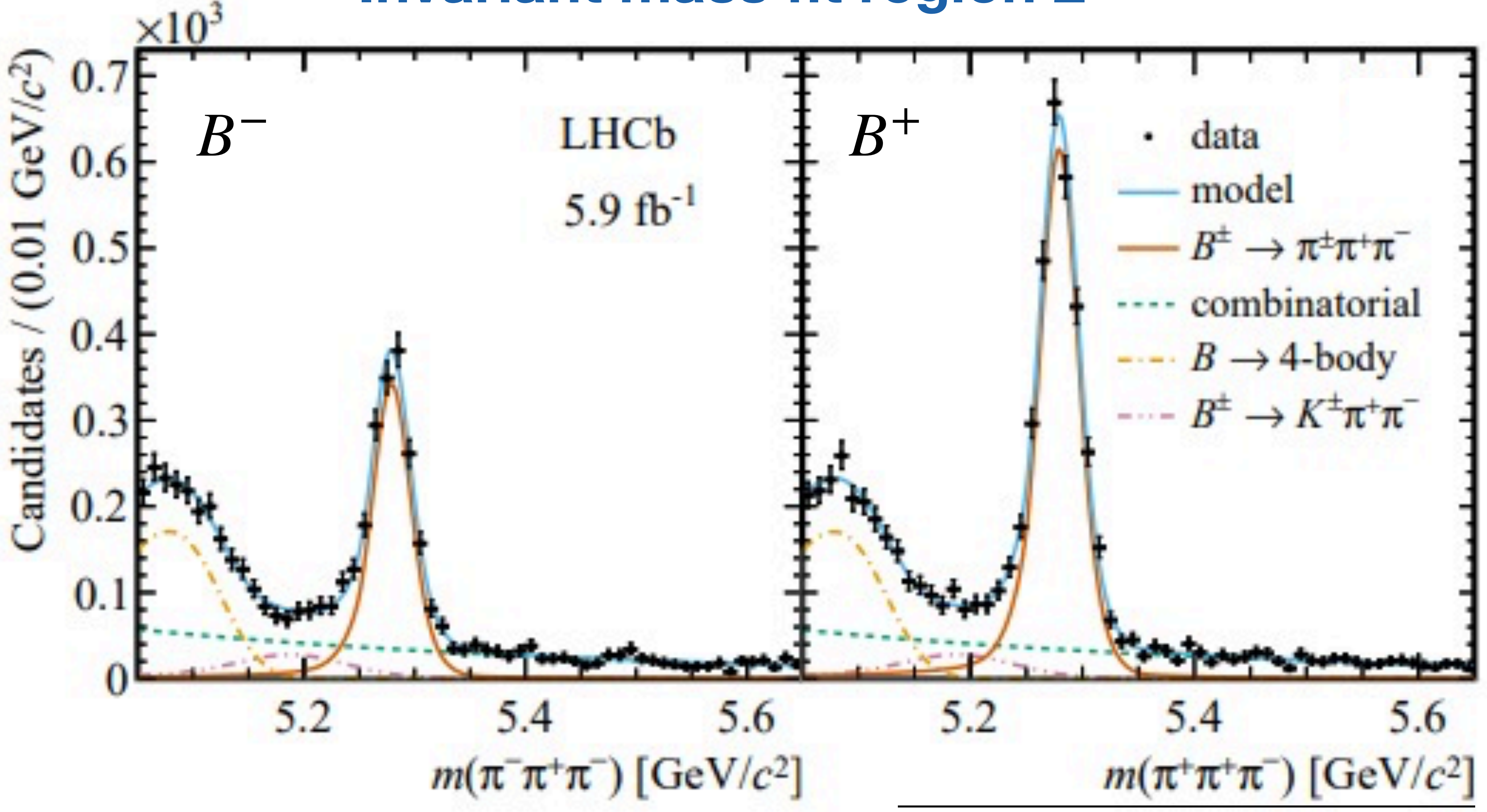
Localized CP asymmetries

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

Invariant mass fit region 1



Invariant mass fit region 2



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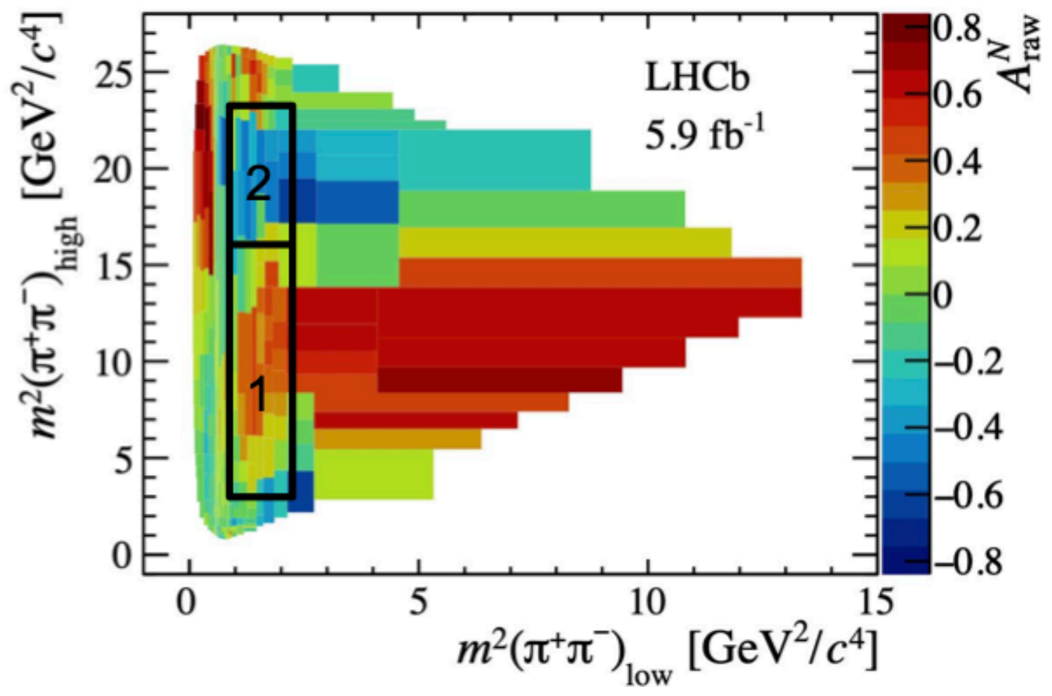
Region 1

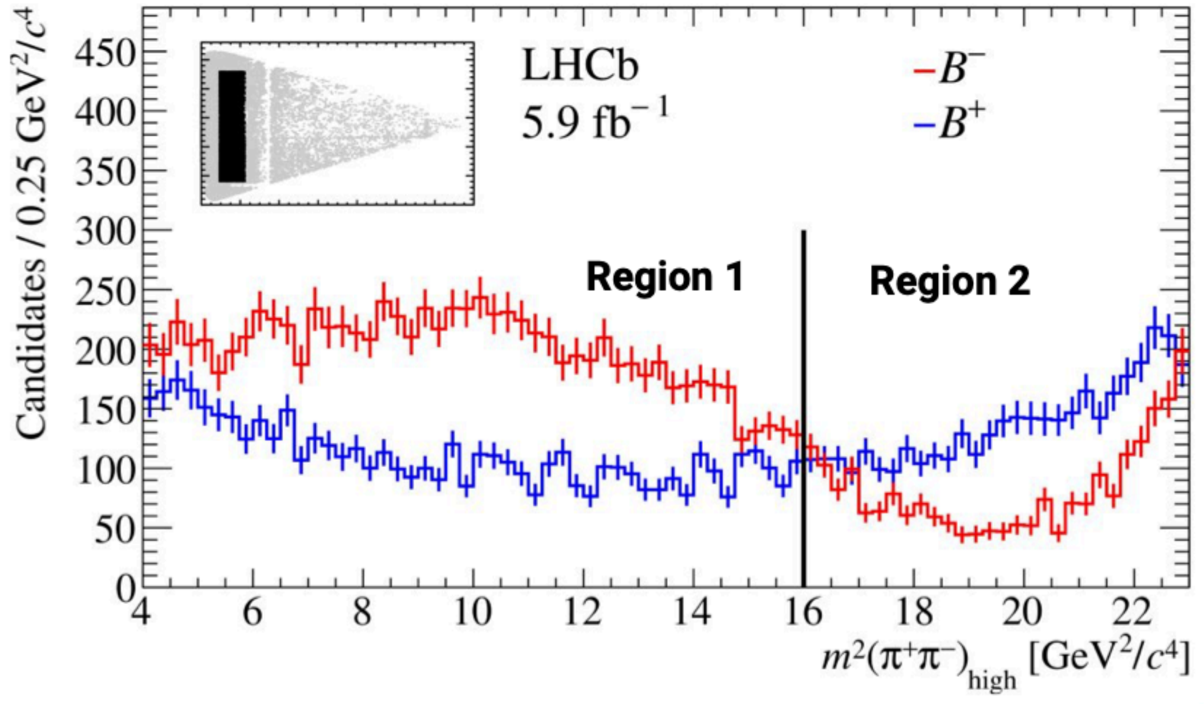
$$A_{CP} = (+30.3 \pm 0.9_{stat} \pm 0.4_{syst} \pm 0.3_{J/\psi K})\ \%$$

Region 2

$$A_{CP} = (-28.4 \pm 1.7_{stat} \pm 0.7_{syst} \pm 0.3_{J/\psi K})\ \%$$

Asymmetry in bins of phase space

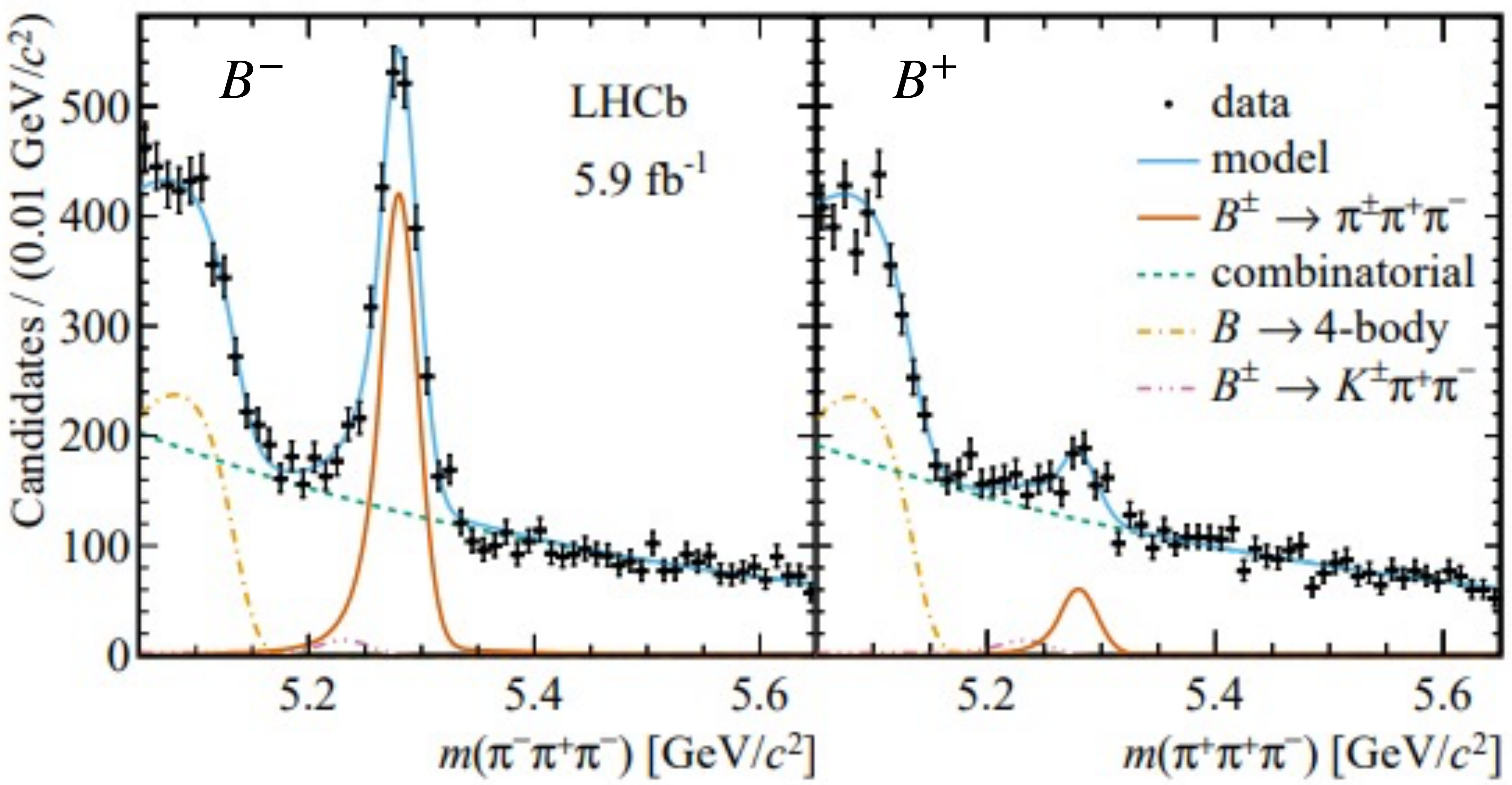




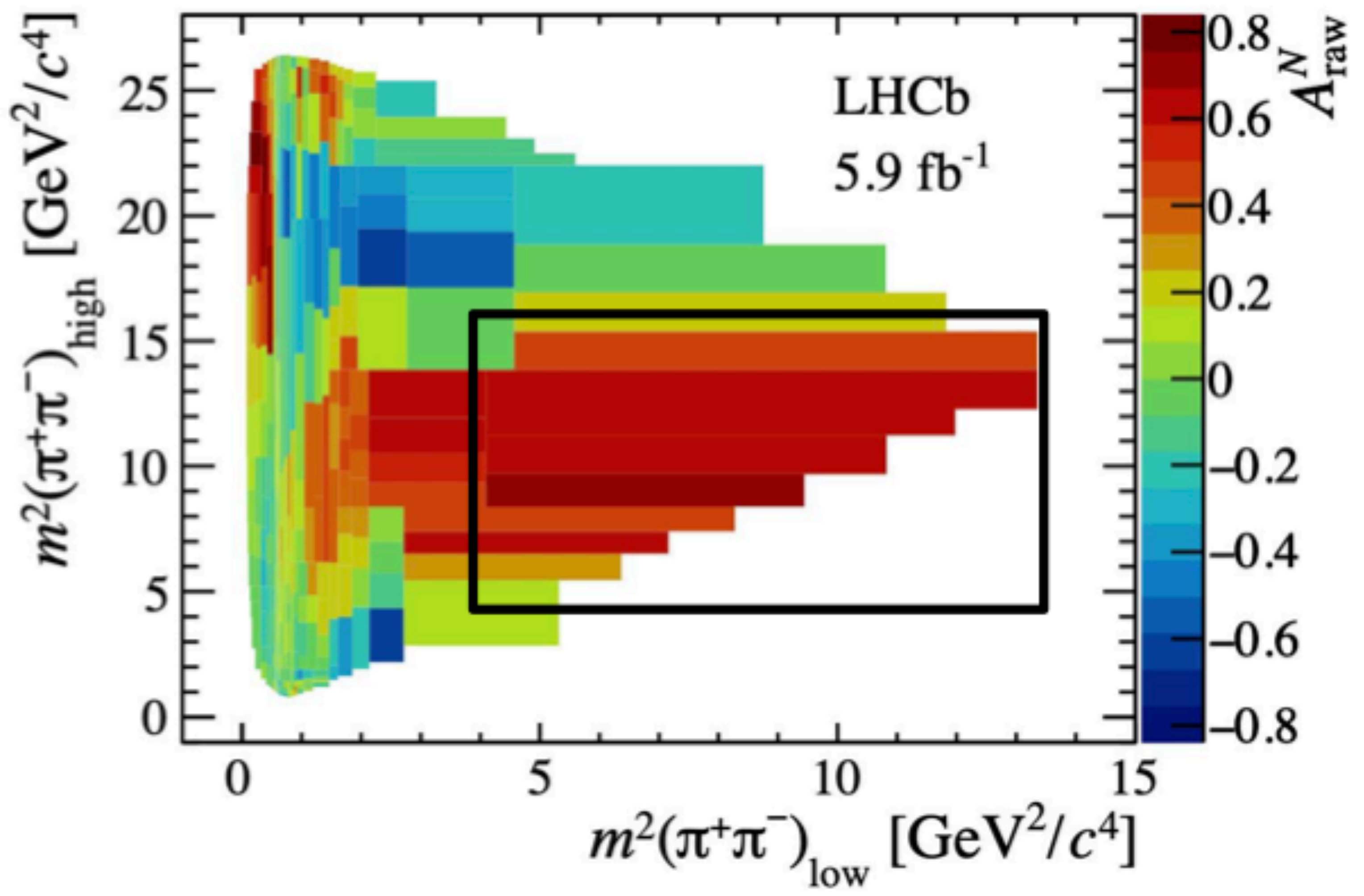
Localized CP asymmetries

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

Invariant mass fit region 3



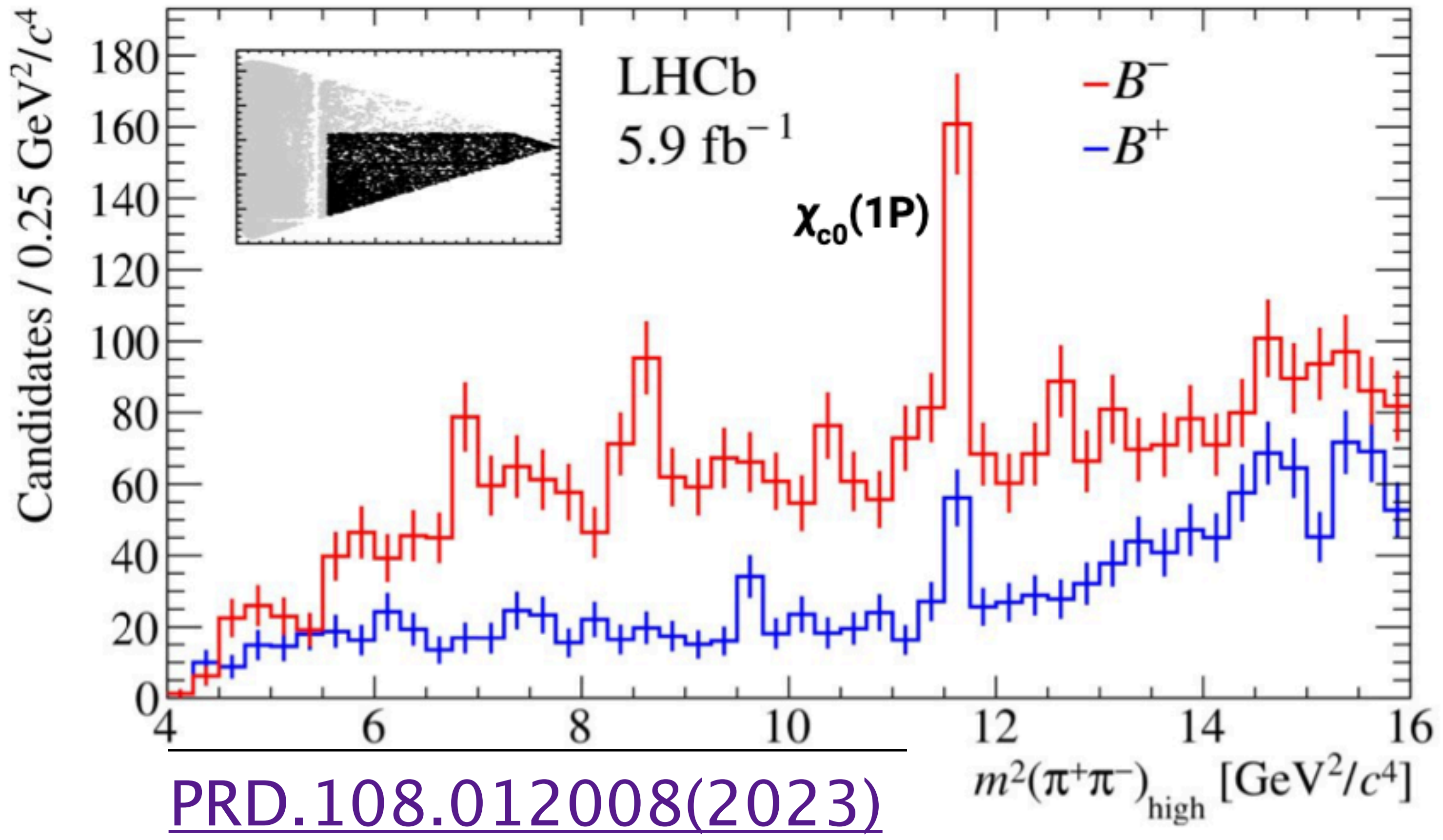
Asymmetry in bins of phase space



Large CPV observed

Region 3

$$A_{CP} = (+74.5 \pm 2.7_{stat} \pm 1.8_{syst} \pm 0.3_{J/\psi K})\ \%$$

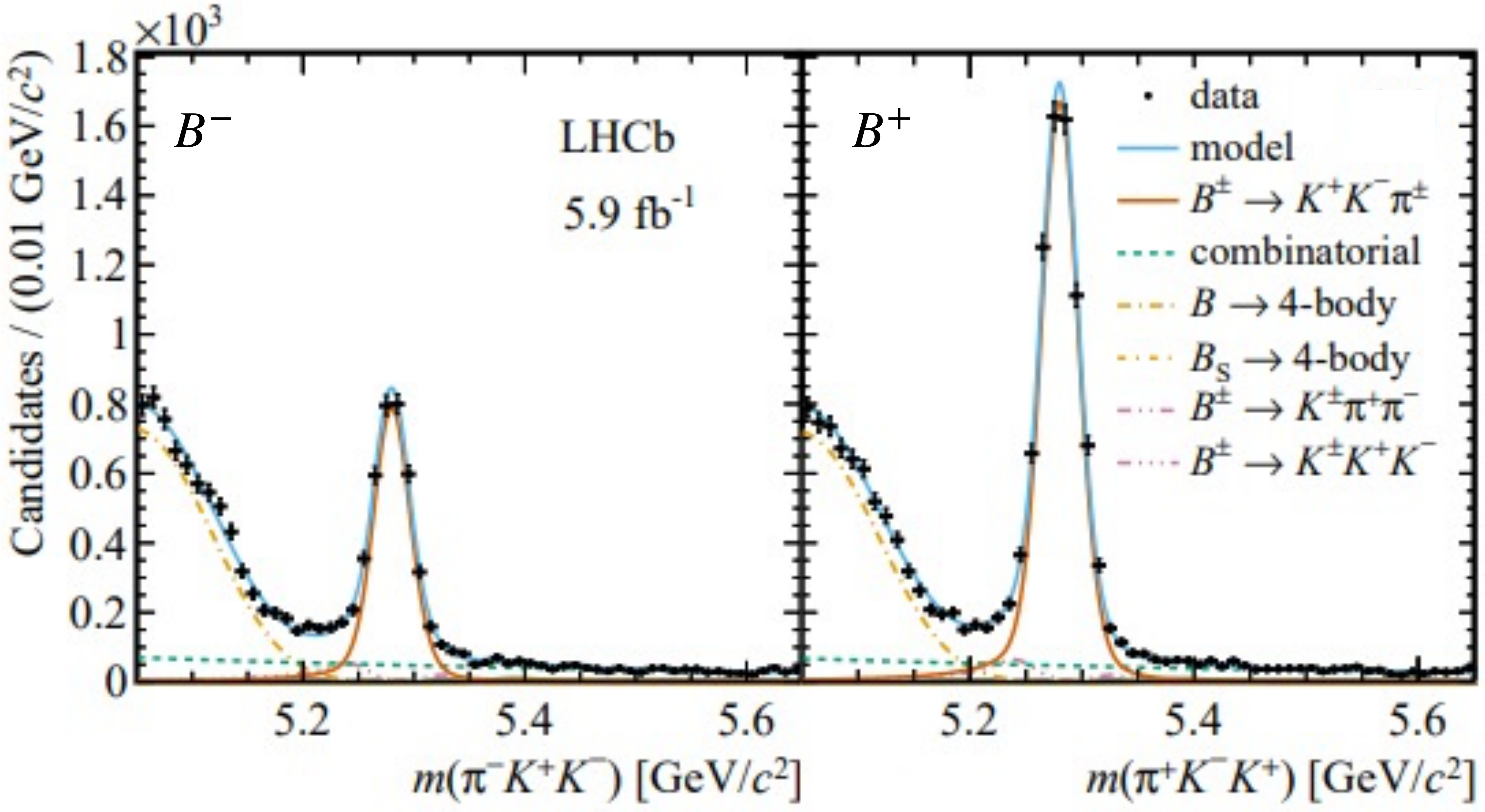


PRD.108.012008(2023)

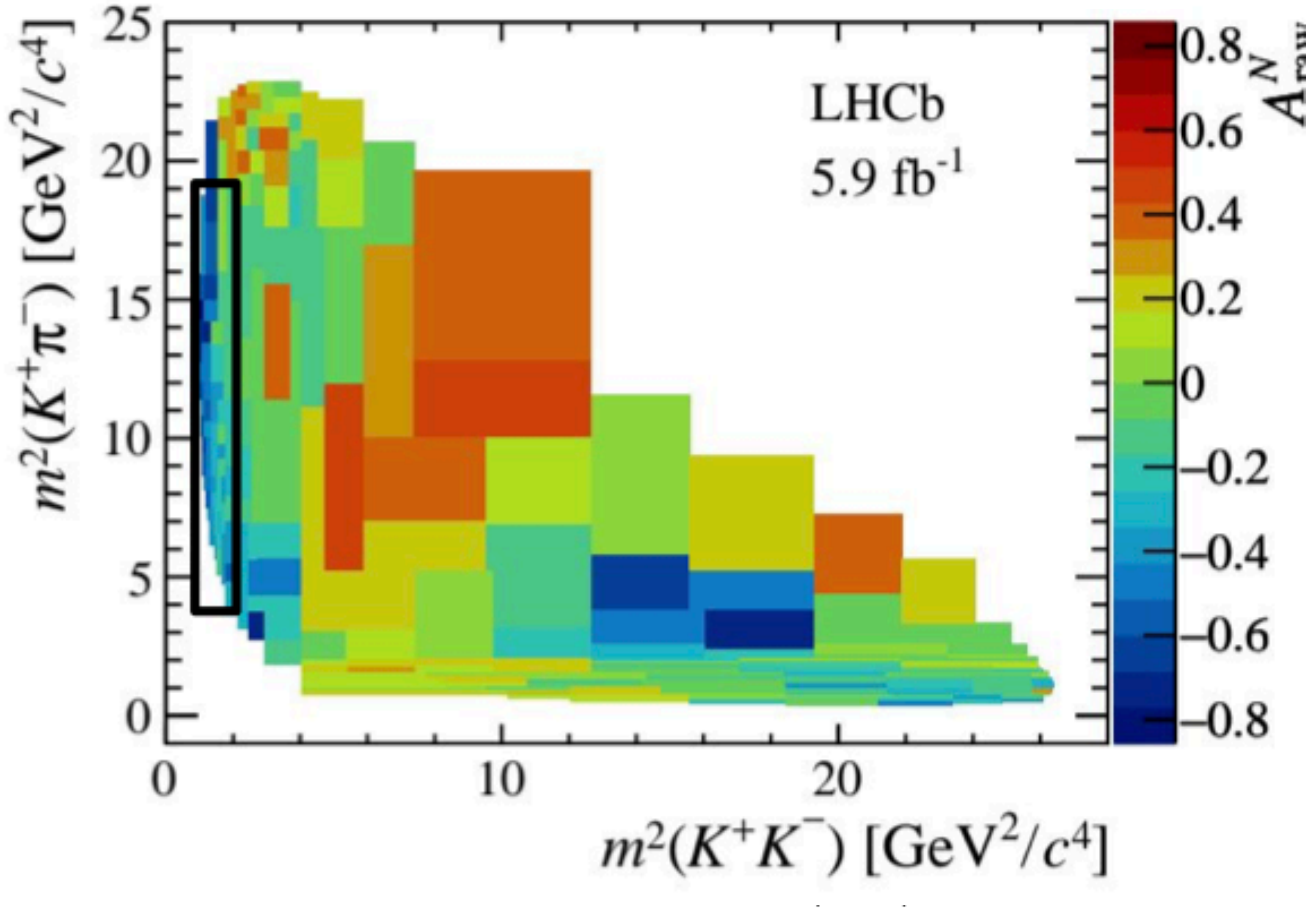
- No direct CPV expected in $\chi_{c0}(1P)$ in SM Phys. Rev. Lett. 74 4984(1995)
  - ☑ Run2 amplitude analysis will provide further details

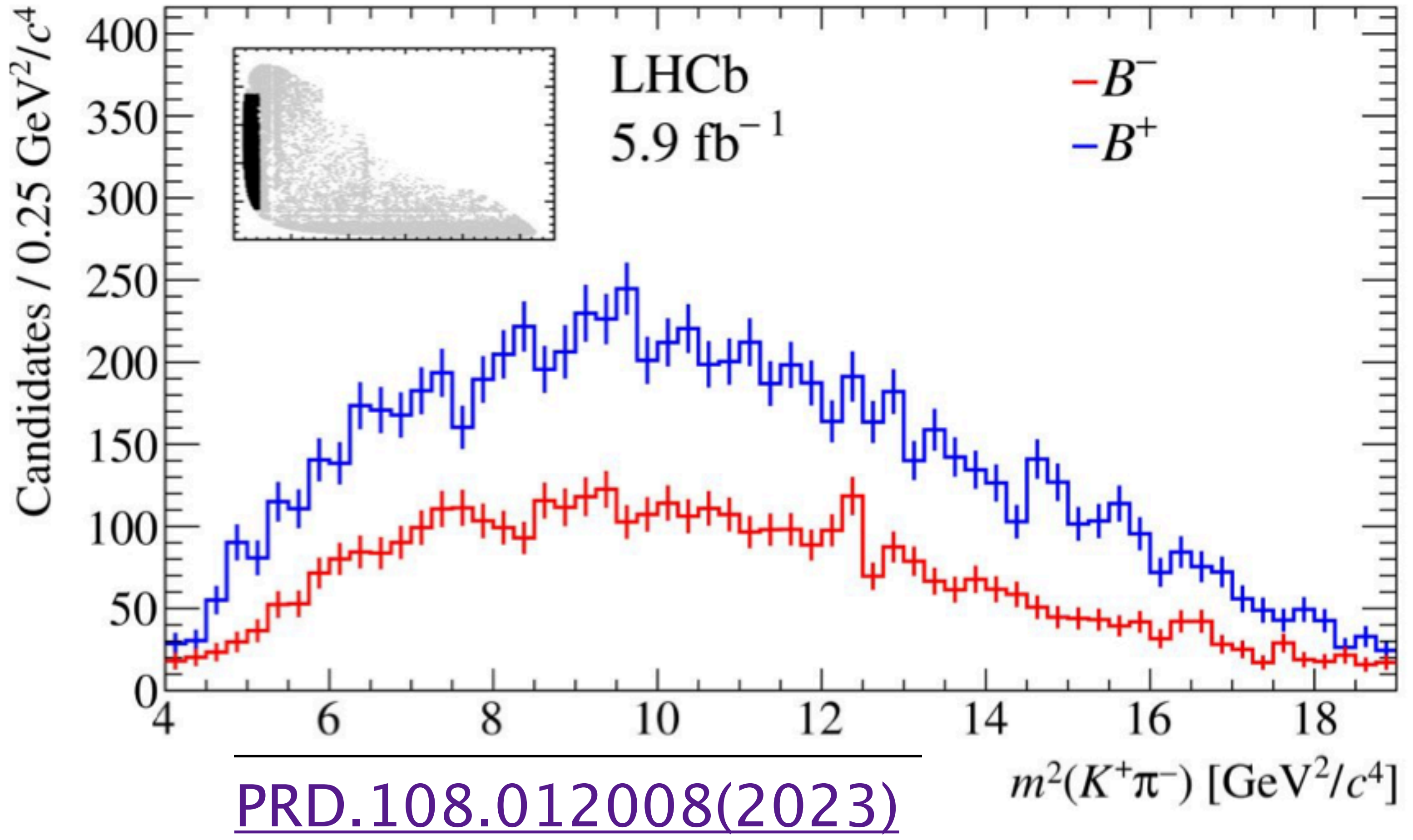
$$B^{\pm} \to \pi^{\pm} K^{+} K^{-}$$

Invariant mass fit Rescattering region



Asymmetry in bins of phase space





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Rescattering Region

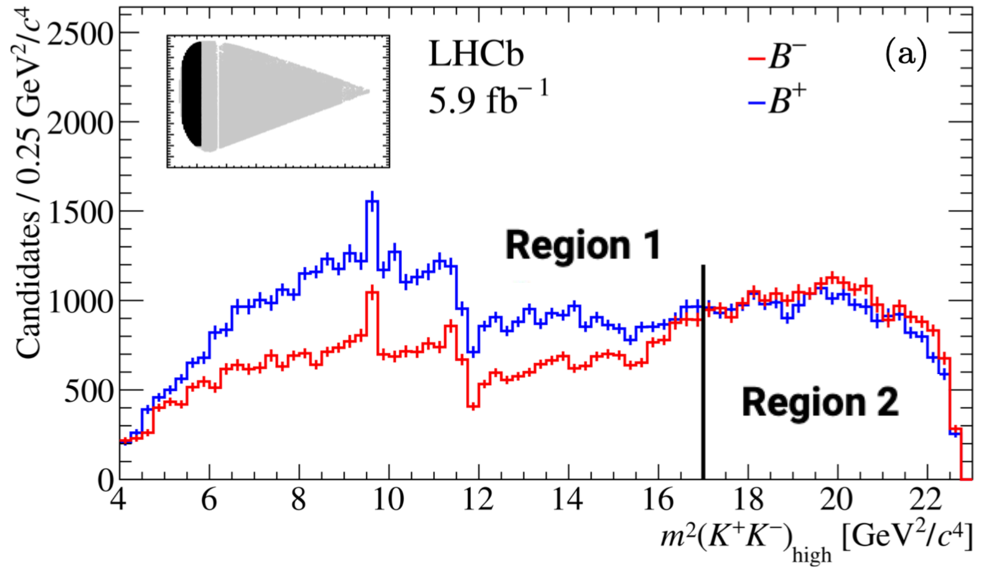
$$A_{CP} = (-35.8 \pm 1.0_{stat} \pm 1.4_{syst} \pm 0.3_{J/\psi K})\ \%$$

- Nearly constant CPV for the Rescattering region
- Features of Rescattering during run I:
  - ☑ Asymmetry of -66%
  - ☑ Fit Fraction of 16%

Phys. Rev. Lett. 123 (2019) 231802

Localized CP asymmetries

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



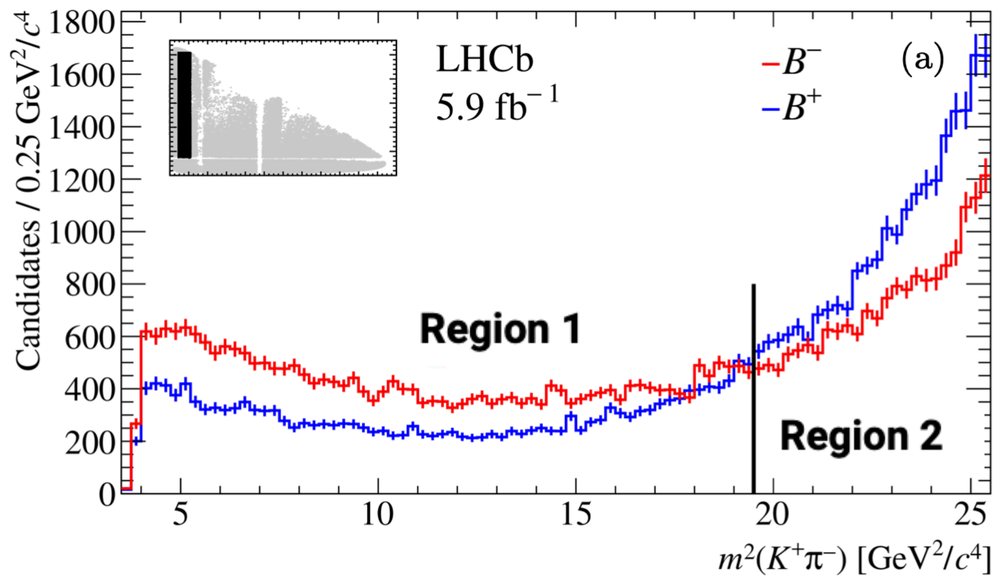
Region 1

$A_{CP} = (-17.8 \pm 0.4_{stat} \pm 0.4_{syst} \pm 0.3_{J/\psi K})\,\%$

Region 2

$A_{CP} = (+4.3 \pm 0.5_{stat} \pm 0.4_{syst} \pm 0.3_{J/\psi K})\,\%$

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



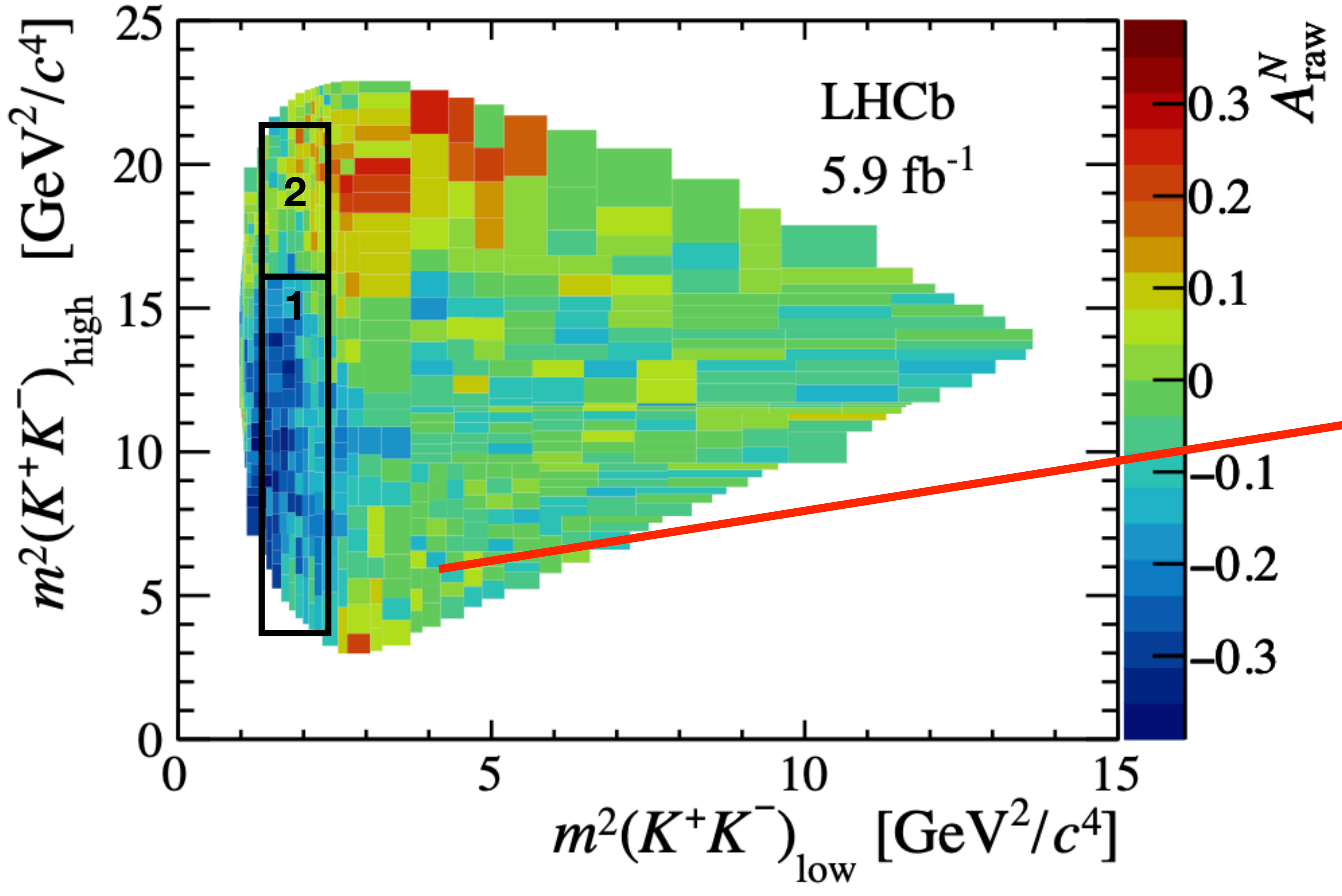
Region 1

$A_{CP} = (+21.7 \pm 0.5_{stat} \pm 0.5_{syst} \pm 0.3_{J/\psi K})\,\%$

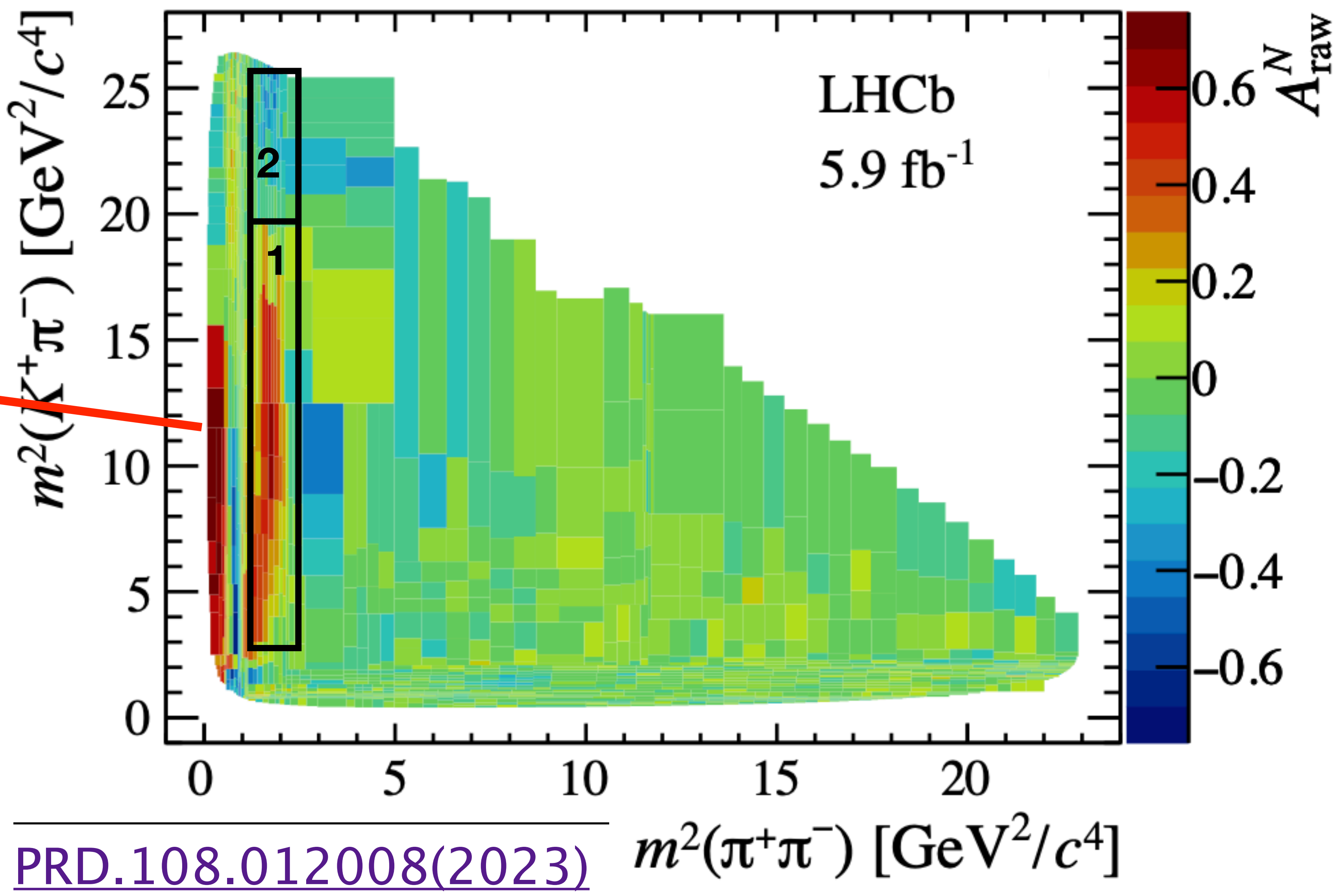
Region 2

$A_{CP} = (-14.5 \pm 0.7_{stat} \pm 0.6_{syst} \pm 0.3_{J/\psi K})\,\%$

Asymmetry in bins of phase space



Asymmetry sign is changing in an opposite direction with respect to each other



PRD.108.012008(2023)

Search for direct CPV in $B \to PV$

$B^{\pm}$ decays into a vector + scalar resonance

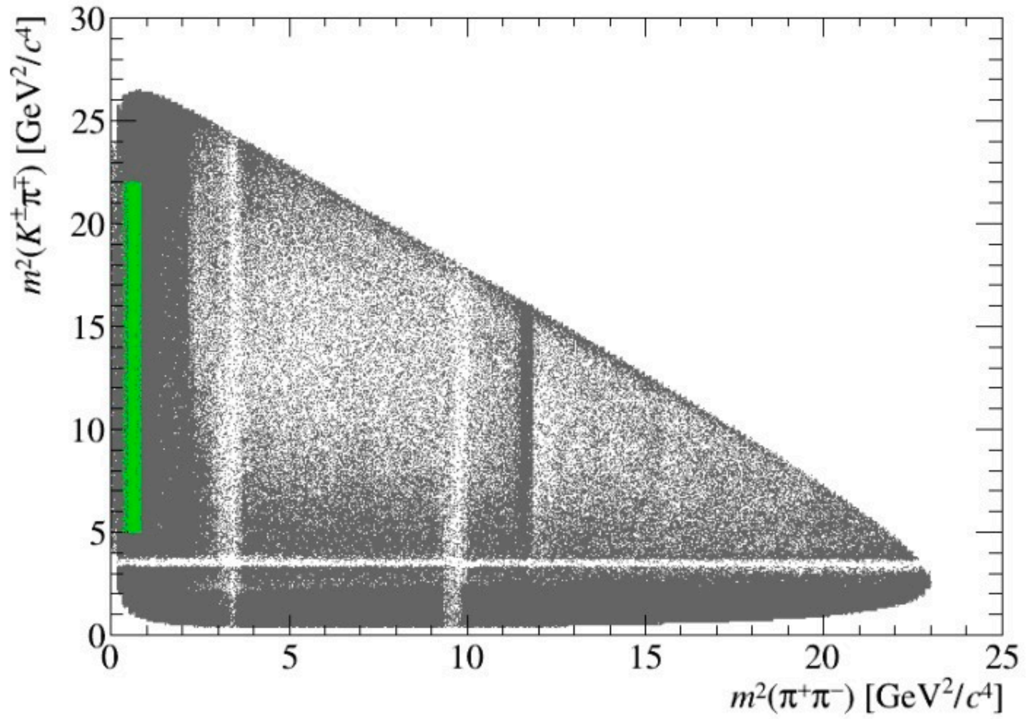
- Motivated by:
  - Great interest involving the CPV in quasi-two-body decays Nucl.Phys.B675(2003)
  - Contribution of short- and long-distance to strong phase
  - This method does not require a full amplitude analyses

- Features of three-body B decays:
  - Large phase-space
  - Dominance of scalars and vectors resonances with low mass
  - Signature of the resonances in the phase-space

- First time this method is used with data PhysRevD.94.054028
  - Method validated with Monte Carlo Simulation

Model independent method

- Select a central mass slice of a vector involving interference with a single scalar



$B^{\pm}$ decays into a vector + scalar resonance

- The decay amplitudes can be represented by: PhysRevD.94.054028

$$\mathcal{M}_{\pm} = a_{\pm}^{V}\, e^{i\delta_{\pm}^{V}}\, F_{V}^{BW}\, cos\theta(s_{\perp}, s_{\parallel}) \;+\; a_{\pm}^{NR}\, e^{i\delta_{\pm}^{NR}}\, F_{NR}^{BW}$$

Assumptions

- $a_{\pm}^{V}$ and $a_{\pm}^{S}$ independent of $s_{\perp}$
- $s_{\parallel} = (p_{h^+} + p_{h^-})^2$

  $s_{\perp} = (p_{h_b} + p_{h^{\pm}})^2$

- The matrix element squared is:

Direct vector A_{CP} — Direct scalar A_{CP}

$$|\mathcal{M}_{\pm}|^2 = (a_{\pm}^{V})^2(\cos\theta)^2|F_{V}^{\mathrm{BW}}|^2 + (a_{\pm}^{S})^2|F_{S}^{\mathrm{BW}}|^2$$

$$+ 2a_{\pm}^{V}a_{\pm}^{S}\cos\theta|F_{V}^{\mathrm{BW}}|^2|F_{S}^{\mathrm{BW}}|^2 \times \{\cos(\delta_{\pm}^{V} - \delta_{\pm}^{S})[(m_{V}^2 - s_{\parallel})(m_{S}^2 - s_{\parallel}) + (m_{V}\Gamma_{V})(m_{S}\Gamma_{S})] + \sin(\delta_{\pm}^{V} - \delta_{\pm}^{S})[(m_{S}\Gamma_{S})(m_{V}^2 - s_{\parallel}) - (m_{V}\Gamma_{V})(m_{S}^2 - s_{\parallel})]\},$$

Scalar and vector interference

$B^{\pm}$ decays into a vector + scalar resonance

- Asymmetry ∝ amplitude square:

Direct scalar A_{CP} — Scalar and vector interference — Direct vector A_{CP}

$$|\mathcal{M}_{\pm}|^2 = p_0^{\pm} + p_1^{\pm} cos\theta(m_V^2, s_\perp) + p_2^{\pm} cos^2\theta(m_V^2, s_\perp)$$

- $B^{\pm} \to (V \to h^+h^-)h^{\pm}$ contributions:
  - ☑ $B^{\pm} \to (\rho(770)^0 \to \pi^+\pi^-)\ \pi^{\pm}$
  - ☑ $B^{\pm} \to (\rho(770)^0 \to \pi^+\pi^-)\ K^{\pm}$
  - ☑ $B^{\pm} \to (K^*(892)^0 \to K^+\pi^-)\ \pi^{\pm}$
  - ☑ $B^{\pm} \to (K^*(892)^0 \to K^+\pi^-)\ K^{\pm}$
  - ☑ $B^{\pm} \to (\phi(1020) \to K^+K^-)\ K^{\pm}$

- Quadratic function to get amplitude parameters:
  - ☑ $f(x) = p_0 + p_1 x + p_2 x^2$

$$A_{CP}^{V} = \frac{|\mathcal{M}_-|^2 - |\mathcal{M}_+|^2}{|\mathcal{M}_-|^2 + |\mathcal{M}_+|^2} = \frac{p_2^- - p_2^+}{p_2^- + p_2^+}$$

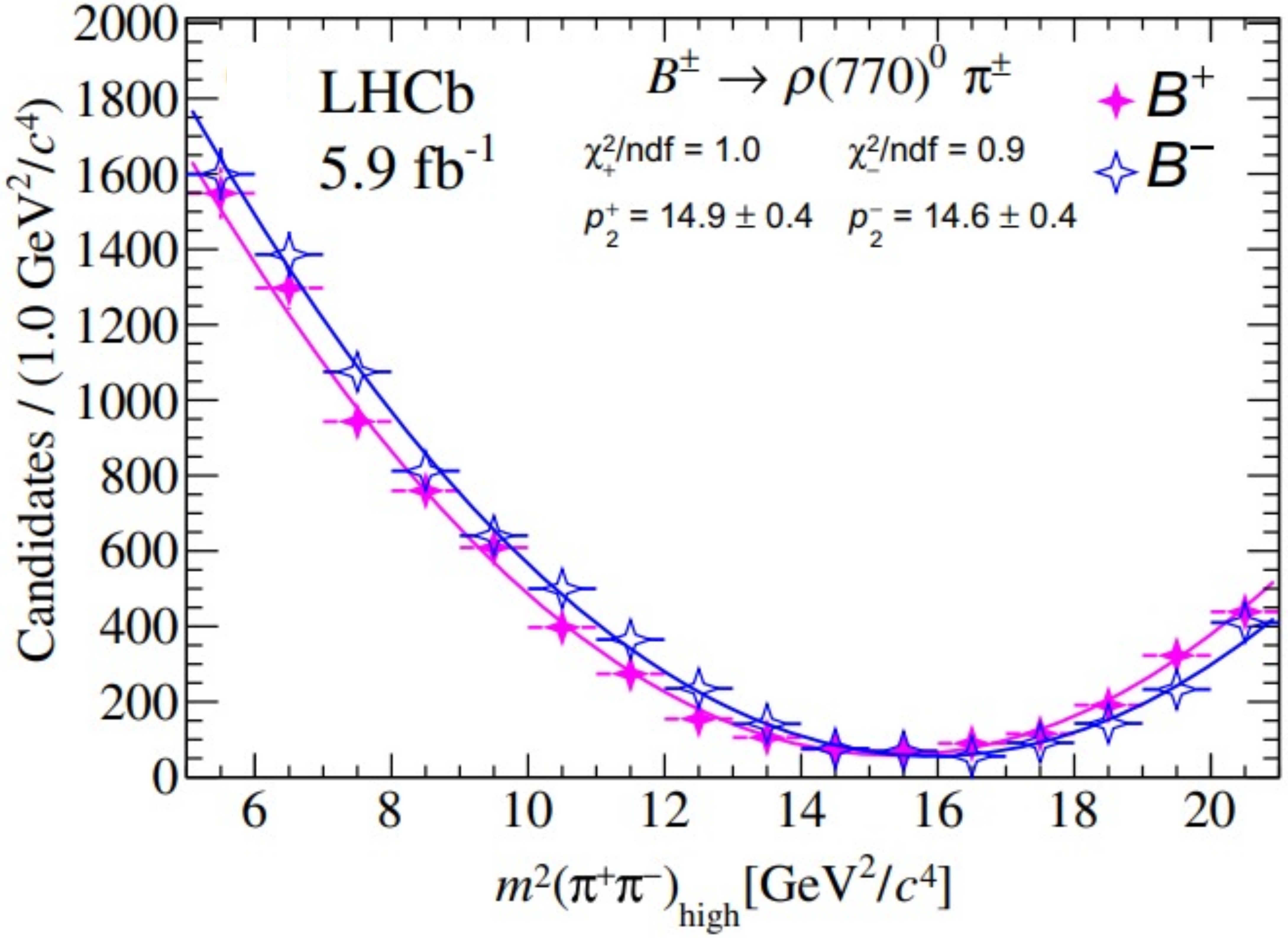
- Given this approximation the A_{CP} can be obtained from the $s_\perp$

$$cos\theta(s_\parallel, s_\perp) \approx cos\theta(m_V^2, s_\perp)$$

$cos\theta$ becomes a linear function of $s_\perp$

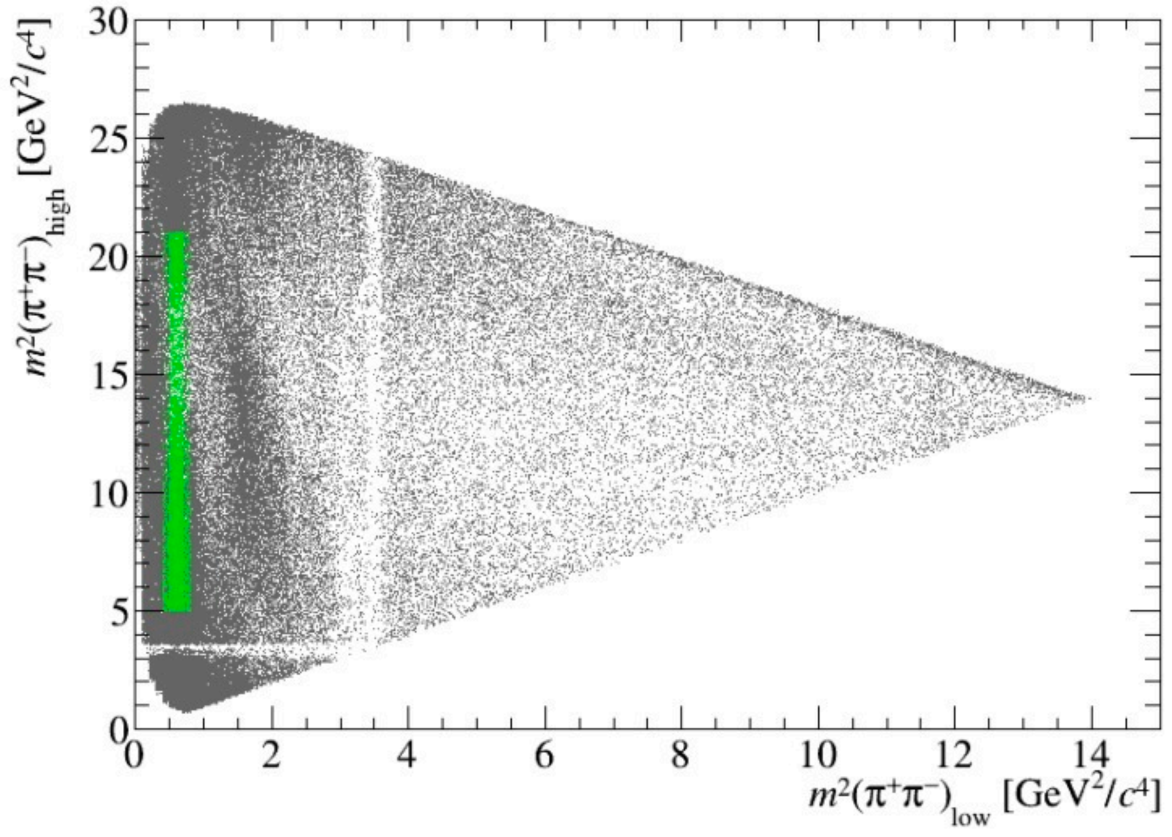
$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$

PRD.108.012013(2023)



$$A_{CP} = (-0.4 \pm 1.7_{stat} \pm 0.9_{syst})\ \%$$

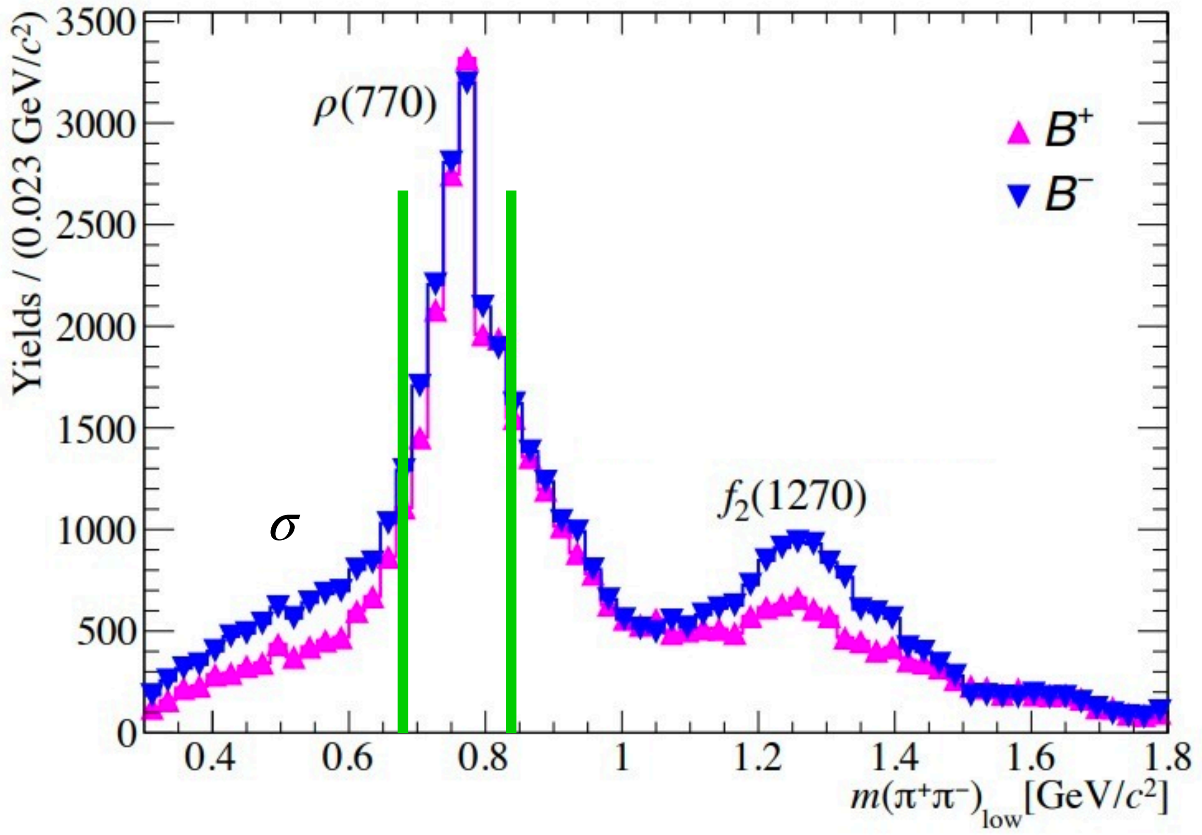
- LHCb previous results: Phys. Rev. Lett. 124(2020) 031801
  - $A_{CP} = (+0.7 \pm 1.1 \pm 1.6)\ \%$



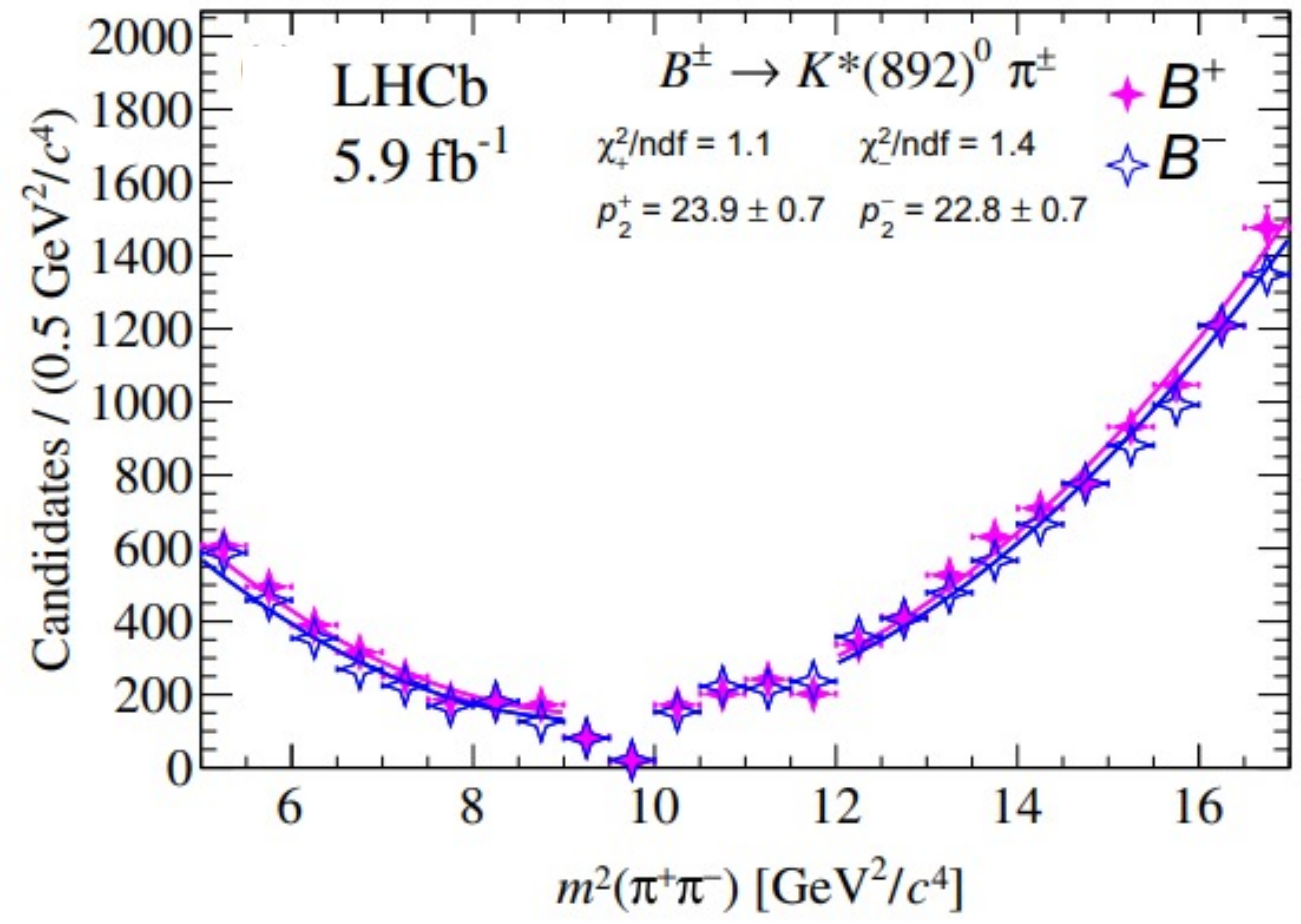
- Selected region

$0.49 < m^2_{\pi^+\pi^-(low)} < 0.72$

$5 < m^2_{\pi^+\pi^-(high)} < 21$

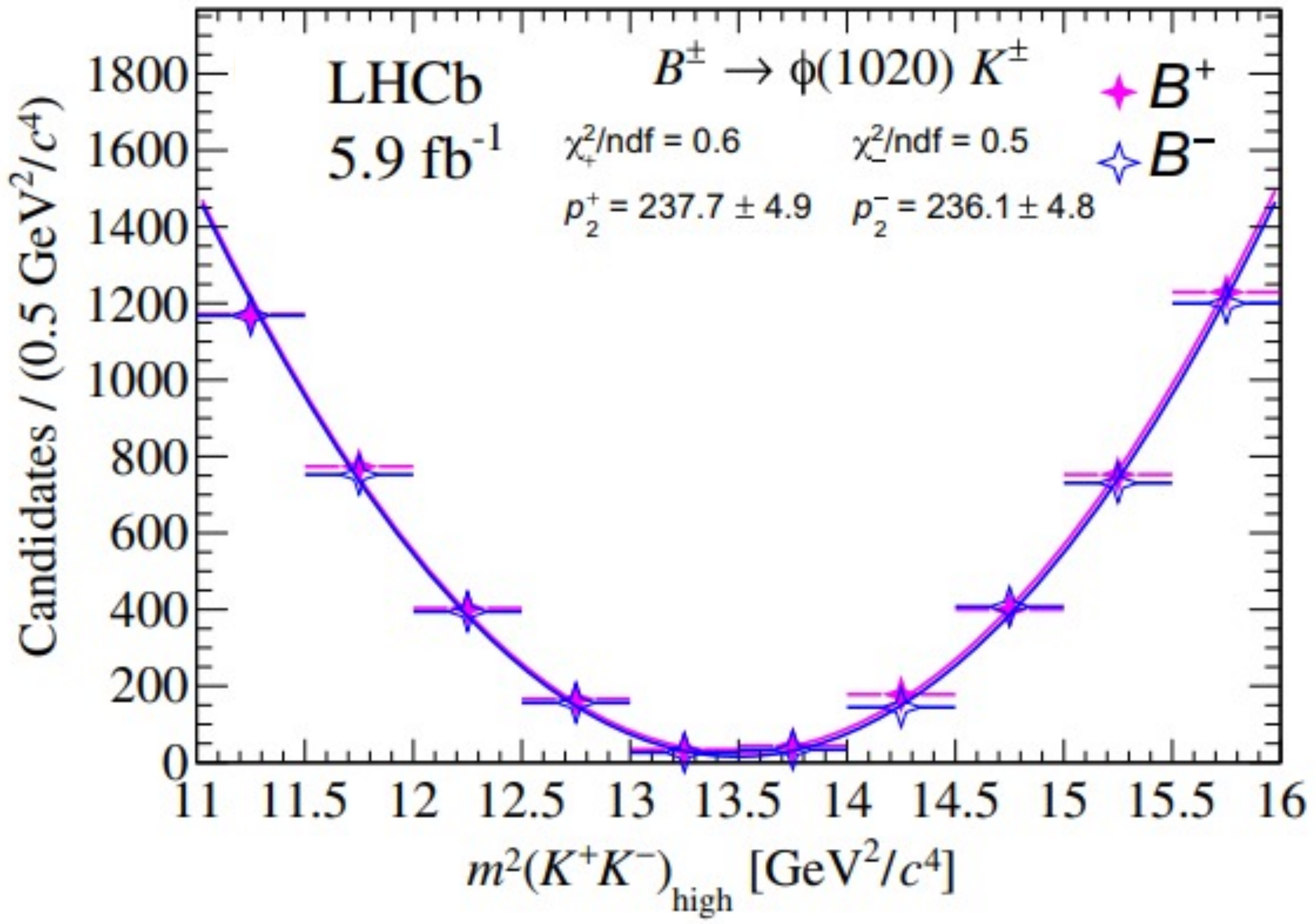


$B^{\pm} \to K^*(892)^0 \pi^{\pm}$



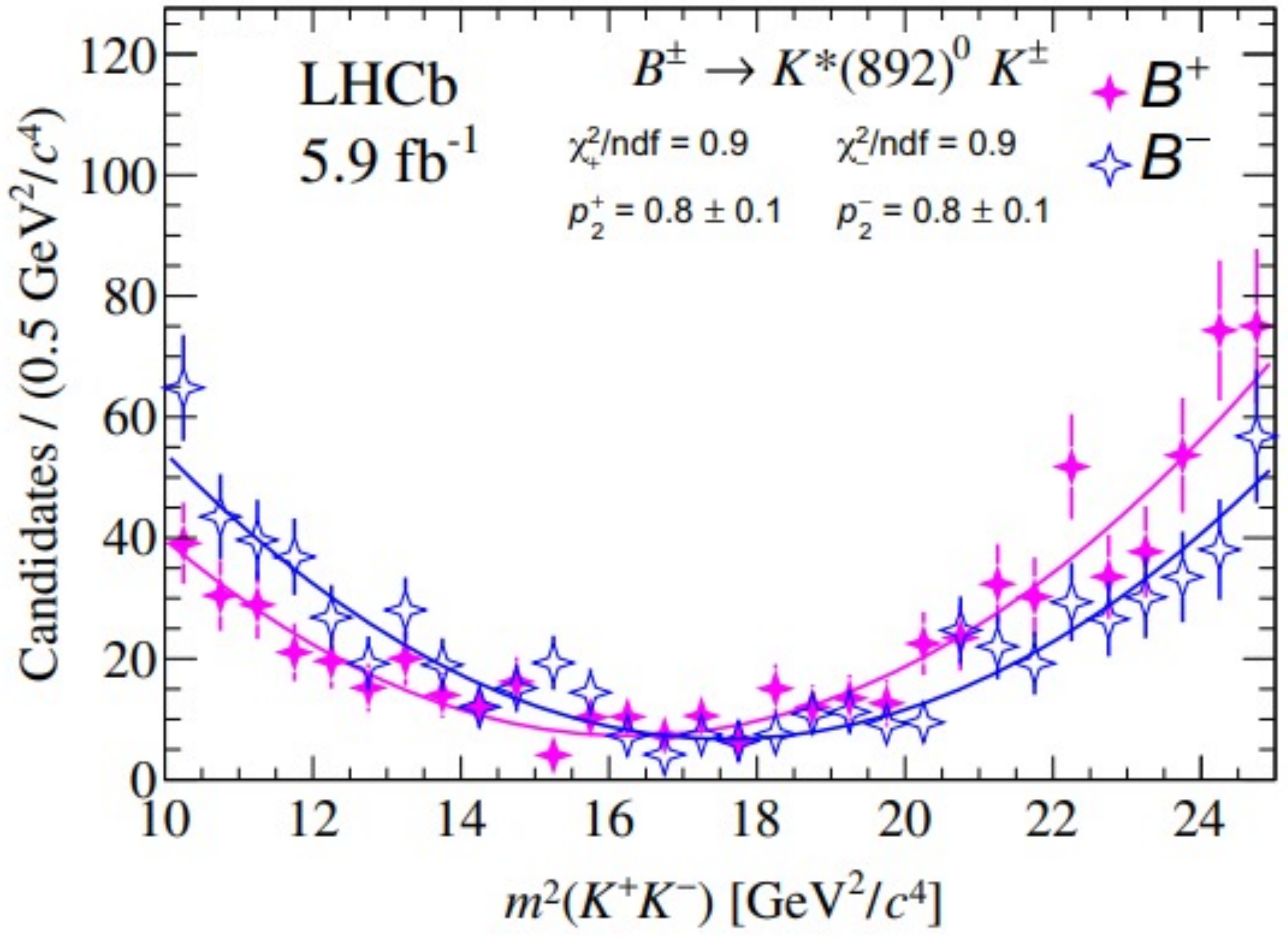
$A_{CP} = (-1.5 \pm 2.1_{stat} \pm 1.2_{syst})\,\%$

$B^{\pm} \to \phi(1020) K^{\pm}$



$A_{CP} = (+0.4 \pm 1.4_{stat} \pm 0.7_{syst})\,\%$

$B^{\pm} \to K^*(892)^0 K^{\pm}$



$A_{CP} = (+0.7 \pm 5.4_{stat} \pm 3.2_{syst})\,\%$

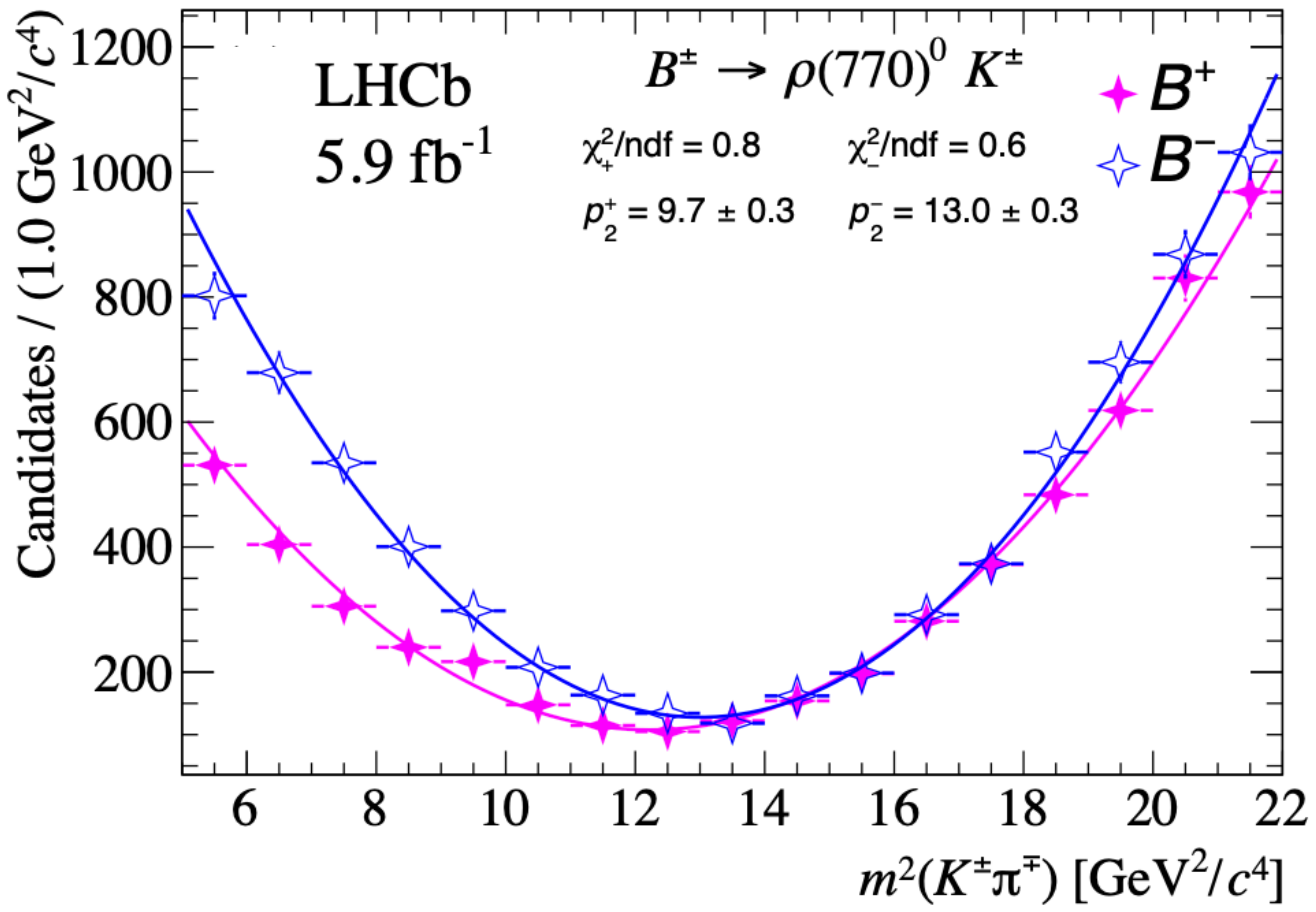
PRD.108.012013(2023)

$B^{\pm} \to \rho(770)^0 K^{\pm}$

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

- Asymmetry in the region dominated by $B^{\pm} \to \rho(770)K^{\pm}$ decays for the **first time observed**
- Large scalar contribution from $f_0(980)$
- Large A_{cp} probably from FSI

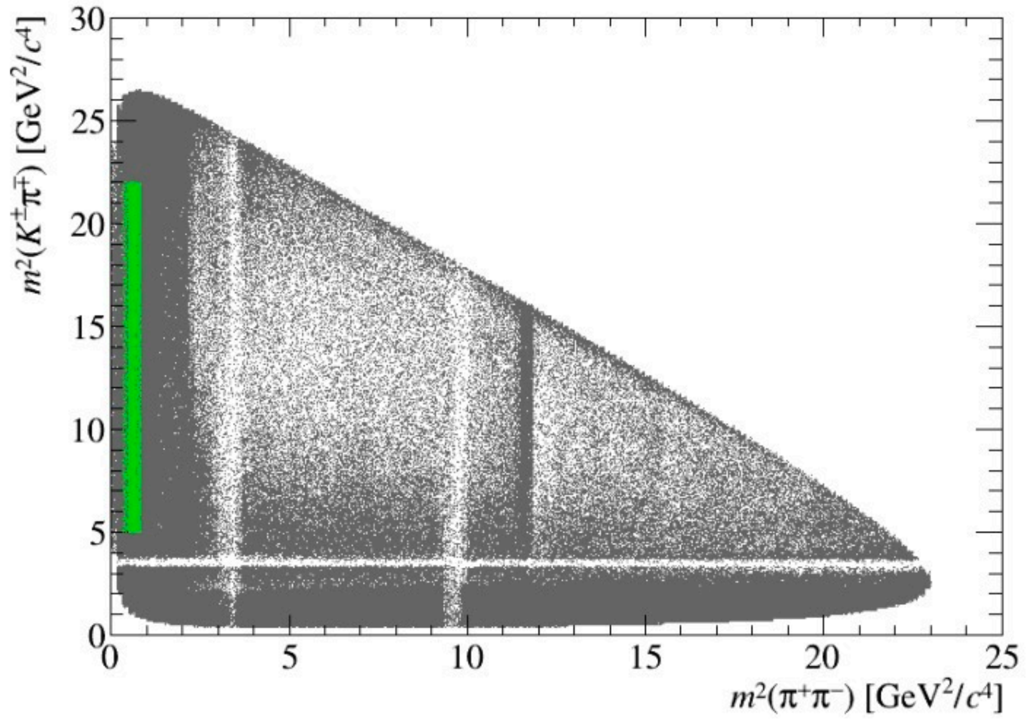
PRD.108.012013(2023)

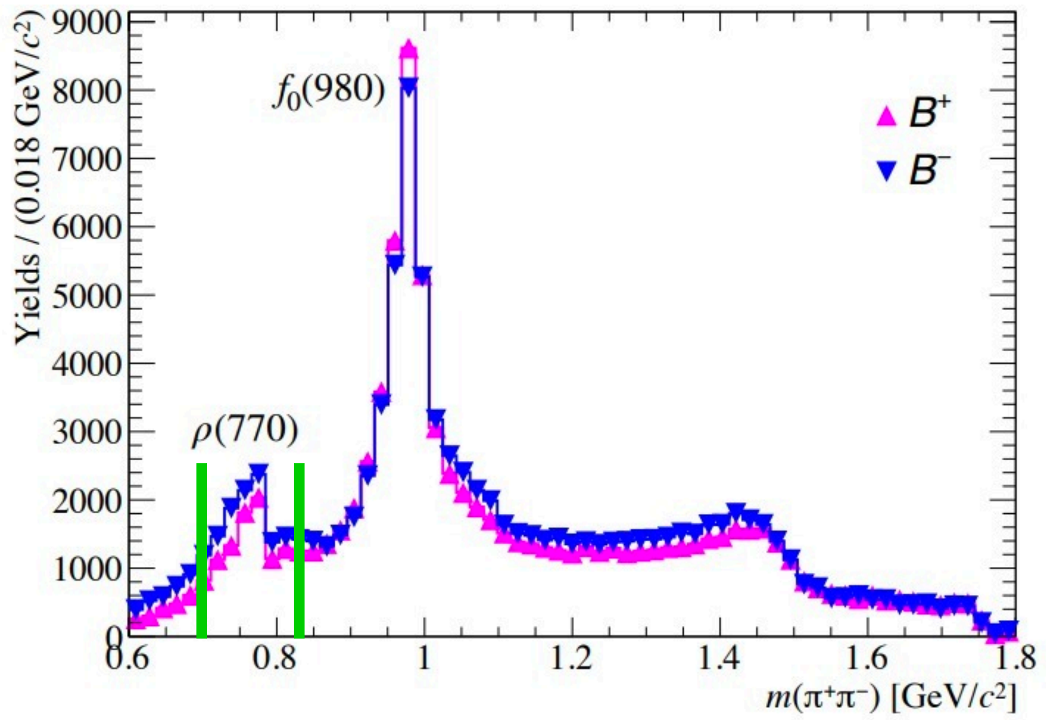


- Selected region

$0.49 < m^2_{\pi^+\pi^-} < 0.72$

$5 < m^2_{K^+\pi^-} < 22$





- Babar results: Phys. Rev. D78 (2008) 012004
  - $A_{CP} = (44 \pm 10 \pm 4^{+5}_{-13})\ \%$ ⟵ 3.7σ
- Belle results: Phys. Rev. Lett. 96 (2006) 251803
  - $A_{CP} = (30 \pm 11 \pm 2^{+11}_{-4})\ \%$ ⟵ 3.9σ

$$A_{CP} = (+15.0 \pm 1.9_{stat} \pm 1.1_{syst})\ \%$$ ⟵ 7.9σ

Final results for all channels:

Decay channel	This work	Previous measurements
$B^{\pm} \to (\rho(770)^0 \to \pi^+\pi^-)\pi^{\pm}$	$-0.004 \pm 0.017 \pm 0.009$	$+0.007 \pm 0.011 \pm 0.016$ (LHCb)
$B^{\pm} \to (\rho(770)^0 \to \pi^+\pi^-)K^{\pm}$	$+0.150 \pm 0.019 \pm 0.011$	$+0.44 \pm 0.10 \pm 0.04$ (BABAR) $+0.30 \pm 0.11 \pm 0.02$ (Belle)
$B^{\pm} \to (K^*(892)^0 \to K^{\pm}\pi^{\mp})\pi^{\pm}$	$-0.015 \pm 0.021 \pm 0.012$	$+0.032 \pm 0.052 \pm 0.011$ (BABAR) $-0.149 \pm 0.064 \pm 0.020$ (Belle)
$B^{\pm} \to (K^*(892)^0 \to K^{\pm}\pi^{\mp})K^{\pm}$	$+0.007 \pm 0.054 \pm 0.032$	$+0.123 \pm 0.087 \pm 0.045$ (LHCb)
$B^{\pm} \to (\phi(1020) \to K^+K^-)K^{\pm}$	$+0.004 \pm 0.014 \pm 0.007$	$+0.128 \pm 0.044 \pm 0.013$ (BABAR)

Conclusion

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

- Measurements of CP asymmetries in charmless three-body:
  - ☑ $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ (First Observation)
  - ☑ $B^{\pm} \to K^{\pm}K^{+}K^{-}$ (First Observation)
  - ☑ $B^{\pm} \to \pi^{\pm}K^{+}K^{-}$ (Confirmation)
  - ☑ $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$ (No asymmetry)
- The phase space reveals non-uniform asymmetries
- Indication of CP violation involving the $\pi\pi \leftrightarrow KK$ rescattering
- Indication of CP violation involving the $\chi_{c0}(1P)$ resonance

$B \to PV$

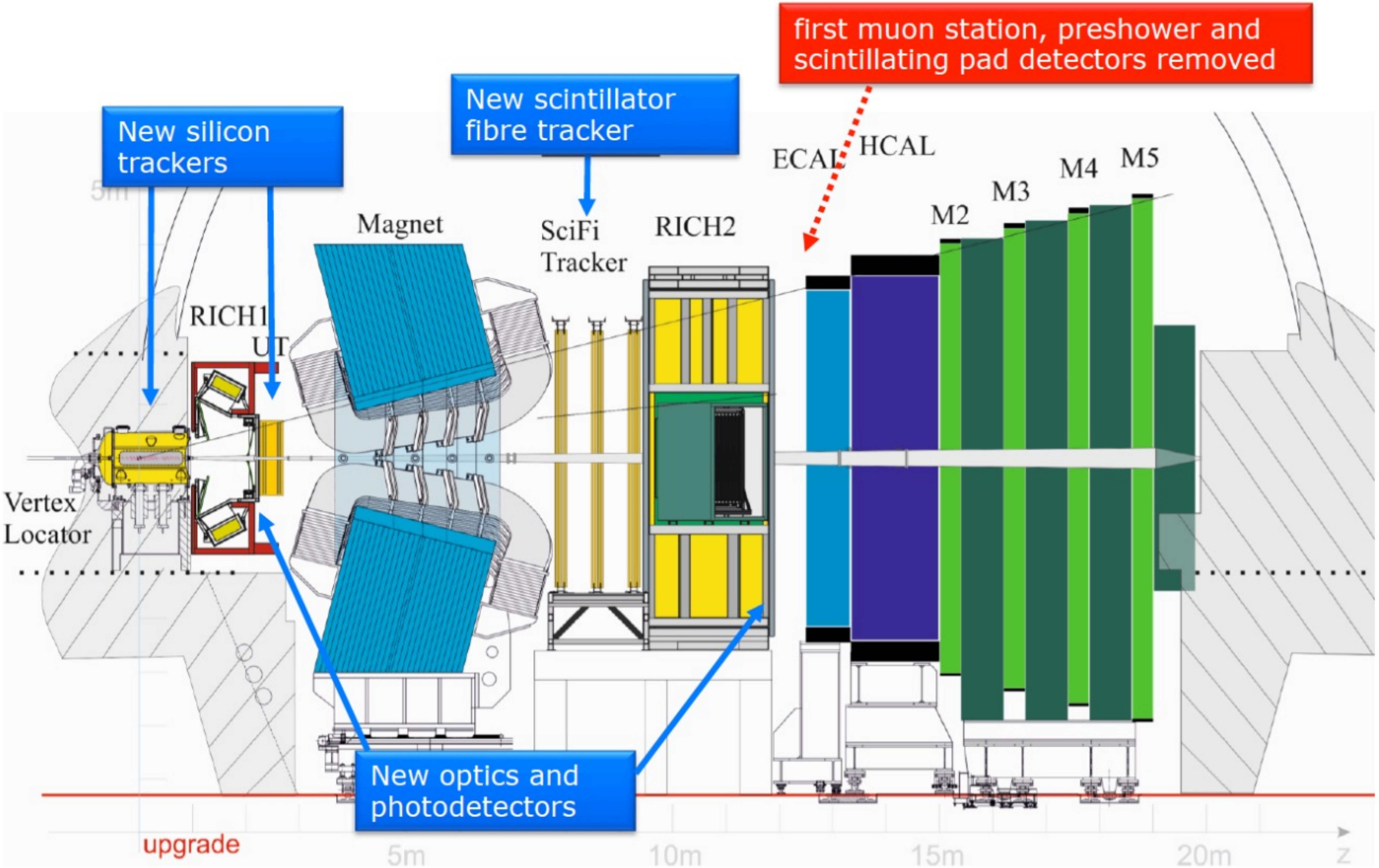
- Measurements of CP asymmetries in $B \to PV$:
  - ☑ New method to measure CPV
  - ☑ $B^{\pm} \to \rho(770)K^{\pm}$ (First Observation)
  - ☑ All other channels (No asymmetry)

Gracias!!!

Thank you!!!

Obrigado!!!

Backup


first muon station, preshower and scintillating pad detectors removed
New scintillator fibre tracker
New silicon trackers
ECAL
HCAL
M2
M3
M4
M5
Magnet
SciFi Tracker
RICH2
RICH1
UT
Vertex Locator
New optics and photodetectors
upgrade
5m
10m
15m
20m
z

Trigger and event selection

Trigger requirements

- Hardware trigger
  - The event is selected if the transverse energy is larger than 3.5 GeV for at least one hadron from the $B^{\pm} \to h^{\pm}h^{+}h^{-}$
- Software trigger
  - Requires a two-, three- or four-track vertex with a significant displacement from any PV

Stripping requirements

Variables	Selection cuts
Tracks P_T	> 0.1 GeV/c
Tracks P	> 1.5 GeV/c
Tracks IPχ^2	> 1
Tracks χ^2/n.d.f.	< 3
Tracks GhostProb	< 0.5
Sum of P_T of tracks	> 4.5 GeV/c
Sum of P of tracks	$> 20.$ GeV/c
Sum of IPχ^2 of tracks	> 500
P_T of the highest-P_T track	> 1.5 GeV/c
Maximum DOCA	< 0.2 mm
$B^{\pm}$ candidate M_{KKK}	$5.05 - 6.30$ GeV/c^2
$B^{\pm}$ candidate M_{KKK}^{COR}	$4 - 7$ GeV/c^2
$B^{\pm}$ candidate IP χ^2	< 10
$B^{\pm}$ candidate P_T	$> 1.$ GeV/c
Distance from SV to any PV	> 3 mm
Secondary Vertex χ^2	< 12
$B^{\pm}$ candidate $\cos(\theta)$	> 0.99998
$B^{\pm}$ Flight Distance χ^2	> 500

Systematic uncertainties

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

- Divided into three groups
  - Potential mismodelling of the invariant mass distribution
  - Phase-space efficiency corrections
  - Production asymmetry

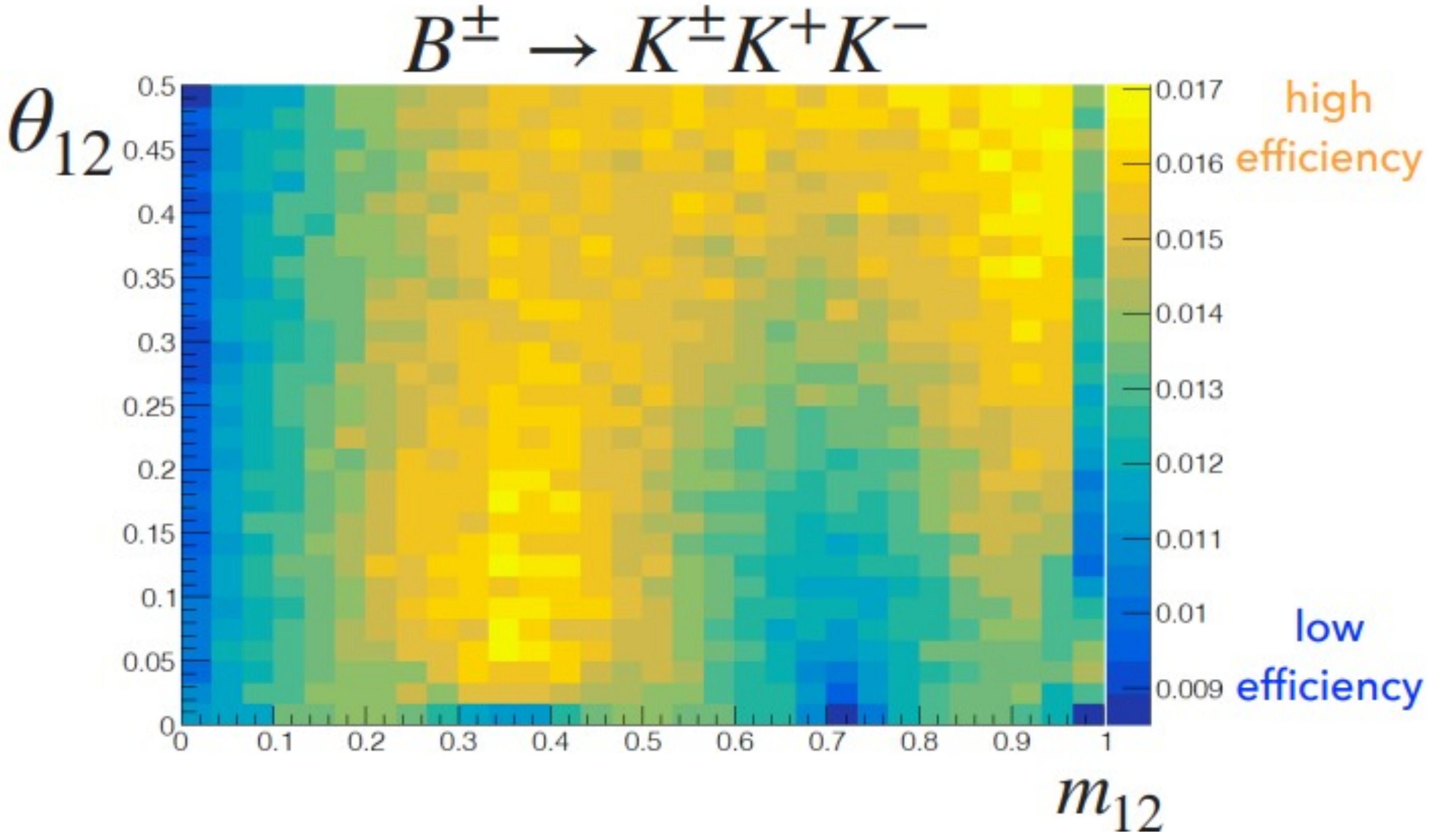
Source of uncertainty	$K^{\pm}\pi^{+}\pi^{-}$	$K^{\pm}K^{+}K^{-}$	$\pi^{\pm}\pi^{+}\pi^{-}$	$\pi^{\pm}K^{+}K^{-}$
Signal model	0.0004	0.0007	0.0000	0.0001
Peaking background fraction	0.0005	0.0010	0.0002	0.0004
Peaking background asymmetry	0.0022	0.0001	0.0005	0.0007
Combinatorial model	0.0002	0.0005	0.0015	0.0025
Efficiency correction	0.0014	0.0016	0.0018	0.0019
Production asymmetry	0.0011	0.0011	0.0011	0.0011
Total	0.0029	0.0024	0.0027	0.0035

$B \to PV$

- Divided into three groups
  - Variation of fit regions
  - Variations of resonance mass window
  - Change of the projected variable

Efficiency correction

- The acceptance maps are generated by data weighted Monte Carlo subsamples of:
  - Year: The acceptance maps are separated by year to account for differences between the periods of data taking.
  - Polarity: Separated by each magnet polarity to take into account the left-right asymmetry of the detector.
  - Trigger configuration: Subsamples of TOS and TISnotTOS to account for possible differences between data and MC with respect to the L0Hadron_TOS efficiency.
  - Charge: Separated by B^+ and B^- candidates



- PID corrections performed using the PIDCalib package using bands of kinematic variables

Partial width difference

- Relation between CPV of the different decay modes
  - Based on U-spin symmetry

$$\Delta\Gamma(B^\pm \to \pi^\pm\pi^+\pi^-) = -\Delta\Gamma(B^\pm \to K^\pm K^+ K^-)$$

$$\Delta\Gamma(B^\pm \to \pi^\pm K^+ K^-) = -\Delta\Gamma(B^\pm \to K^\pm\pi^+\pi^-)$$

- The above relations can be rewritten like:

$$\Delta\Gamma(B^\pm \to \pi^\pm K^+ K^-) = \frac{A_{CP}(B^\pm \to \pi^\pm K^+ K^-)\mathcal{B}(B^\pm \to \pi^\pm K^+ K^-)}{\tau(B^\pm)}$$

- Using the measures values of the integrated asymmetry

$$\frac{A_{CP}(B^\pm \to \pi^\pm K^+ K^-)\mathcal{B}(B^\pm \to \pi^\pm K^+ K^-)}{A_{CP}(B^\pm \to K^\pm\pi^+\pi^-)\mathcal{B}(B^\pm \to K^\pm\pi^+\pi^-)} = -0.92 \pm 0.18$$

$$\frac{A_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-)\mathcal{B}(B^\pm \to \pi^\pm\pi^+\pi^-)}{A_{CP}(B^\pm \to K^\pm K^+ K^-)\mathcal{B}(B^\pm \to K^\pm K^+ K^-)} = -1.06 \pm 0.08$$

→ Both results are consistent with -1 as predicted by the U-spin symmetry