CP violation and CPT invariance in charmless B decays

Ignacio Bediaga: Centro Brasileiro de Pesquisas Físicas.

Future Challenges in Non-Leptonic B Decays: Theory and Experiment

General questions about CP Violation.

$\not{CP}$ violation and the CPT Theorem

Valid to any Lorentz invariant theory where the observables are represented for hermitian operators. (Greengerg PRL89 (2002) 231602).

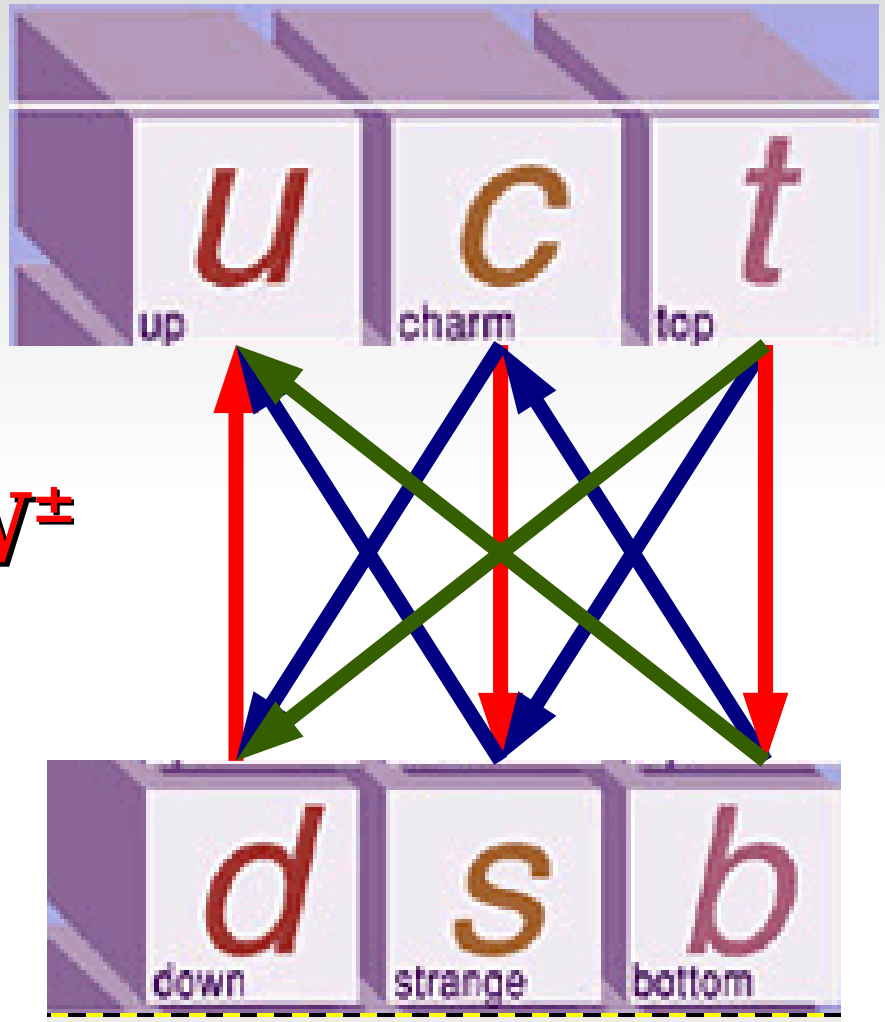
CPT conservation → same lifetime for both, particle and anti-particle.

Sum of the partial width from particle and anti-particle must be the same:

$$\Gamma(M^+ \to f^+_1) + \ldots\ldots + \Gamma(M^+ \to f^+_n) = \Gamma(M^- \to f^-_1) + \ldots\ldots + \Gamma(M^- \to f^-_n)$$

$\not{CP}$ violation → presence of weak phase

CabbiboKobayashiMaskawa Matrix



High probability

Middle probability

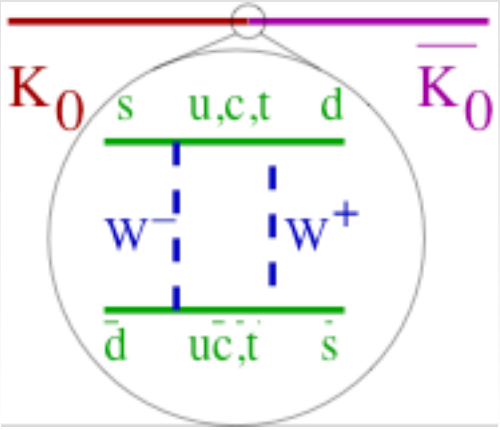
Low probability

$$\begin{array}{c} \begin{array}{ccc} d & s & b \end{array} \\ \begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix} \begin{array}{c} u \\ c \\ t \end{array} \end{array}$$

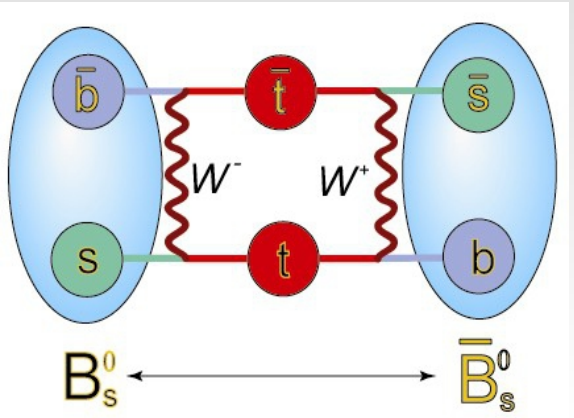
Cabibbo Kobayashi-Maskawa: 4 parameters, 3 angles and one phase.

Particle and anti-particle oscillation

$K^0 \rightleftarrows \overline{K}^0$



$B_s^0 \rightleftarrows \overline{B}_s^0$

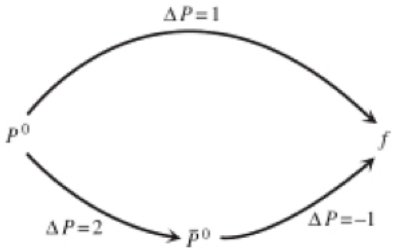


CP violation: Neutral particle and anti-particle decaying into a same final state: (P.ex. $\pi^+\pi^-$, $J/\Psi\, K^0$ or K^+K^-)

Master Equation:

$$\langle \alpha \mid T(t) \mid P^0 \rangle = e^{-(\Gamma/2 - i\Delta m)t} [\, T(P^0 \rightarrow \alpha) \cos \Delta m t + q/p\, T(\bar{P}^0 \rightarrow \alpha) \sin \Delta m t]$$

$$\langle \alpha \mid T(t) \mid \bar{P}^0 \rangle = e^{-(\Gamma/2 - i\Delta m)t} [\, T(\bar{P}^0 \rightarrow \alpha) \cos \Delta m t + p/q\, T(P^0 \rightarrow \alpha) \sin \Delta m t]$$



IF $q/p \neq p/q \rightarrow$ CP violation.

Δm mass difference between B^0 and $\overline{B}^0$

Direct CP violation charged particles:

Different disintegration behaviour from particle and anti-particle

Two contribution to a same final state.

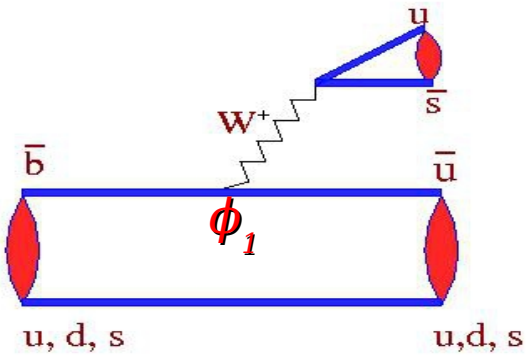
With different strong phases (δ_1 and δ_2) and weak phases (ϕ_1 and ϕ_2).

$$A(B \to f) = A_1 e^{i\phi_1} e^{i\delta_1} + A_2 e^{i\phi_2} e^{i\delta_2} ,$$
$$A(\bar{B} \to \bar{f}) = A_1 e^{-i\phi_1} e^{i\delta_1} + A_2 e^{-i\phi_2} e^{i\delta_2} .$$

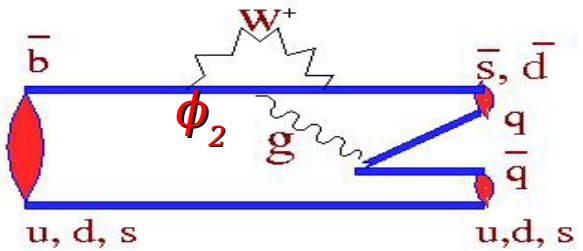
CP Violation:
Datta presentation

$$\Gamma(i \to f) - \Gamma(\bar{i} \to \bar{f}) = |\langle f|T|i\rangle|^2 - |\langle \bar{f}|T|\bar{i}\rangle|^2 = -4A_1A_2 \sin(\delta_1 - \delta_2)\sin(\phi_1 - \phi_2)$$

So CP Violation needs: different strong δ_1 and δ_2 and weak phases ϕ_1 and ϕ_2.



Interference=>CP

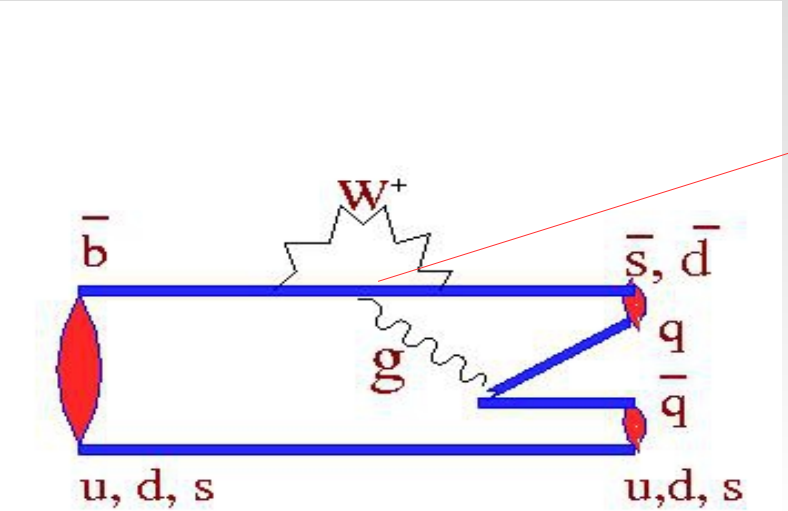


Short distance: BSS Model Bander Silverman and Soni PRL 43 (1979) 242

The weak coming from **CKM** and the strong from **Penguin with time-like gluon.**

Penguin strong phase (short distance).

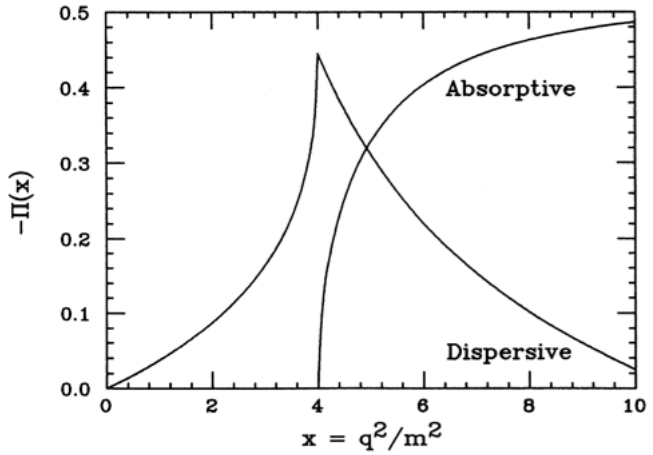
M, Bander, D. Silverman, A. Soni (BSS): Phys.Rev.Lett. 43 (1979) 242



quarks u,c and t

- Real and imaginary part of Penguin diagram change with the q^2 of the gluon.

$$F_1^i(q^2) = -4\left[\frac{1}{6}\ln\frac{m_i^2}{M_W^2} + \Pi\left[\frac{q^2}{m_i^2}\right]\right]$$



Π (q^2/m_i^2) is a long expression presented in ref.

Gerard and Hu,Phys. Rev. V43D, 2909 (1991).

The graphic representation is:

Significant contribution from only c quark and for for $q^2 > m_c^2$

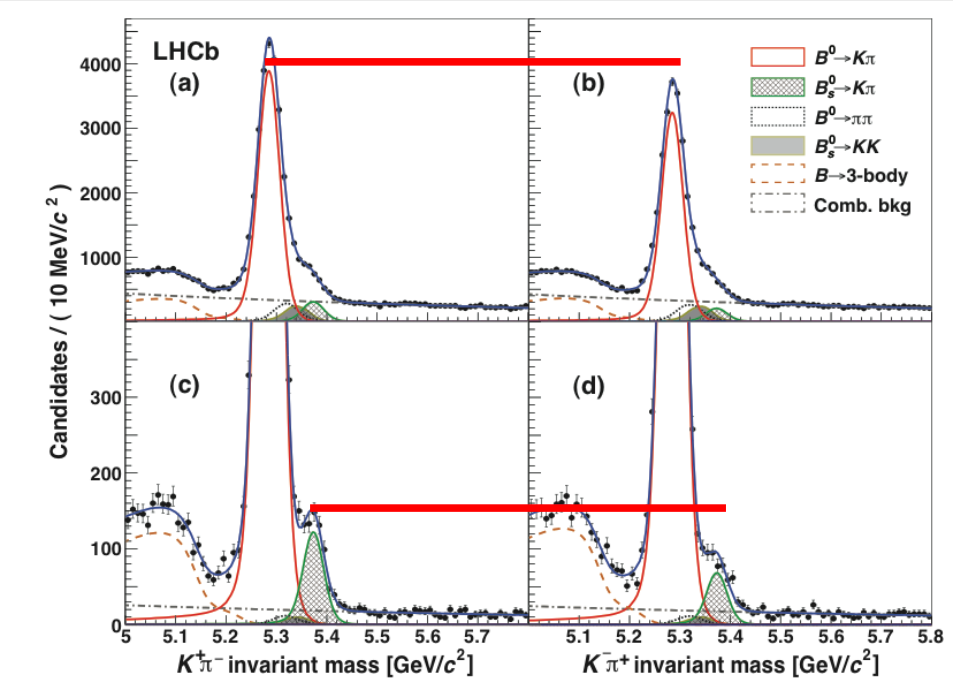
Directly CP violation for :

$B^0 \rightarrow K^+\pi^-$ e $B^0_s \rightarrow K^+\pi^-$

LHCb: *Phys. Rev. Lett. 110, 221601 (2013)*

Directly CP violation:

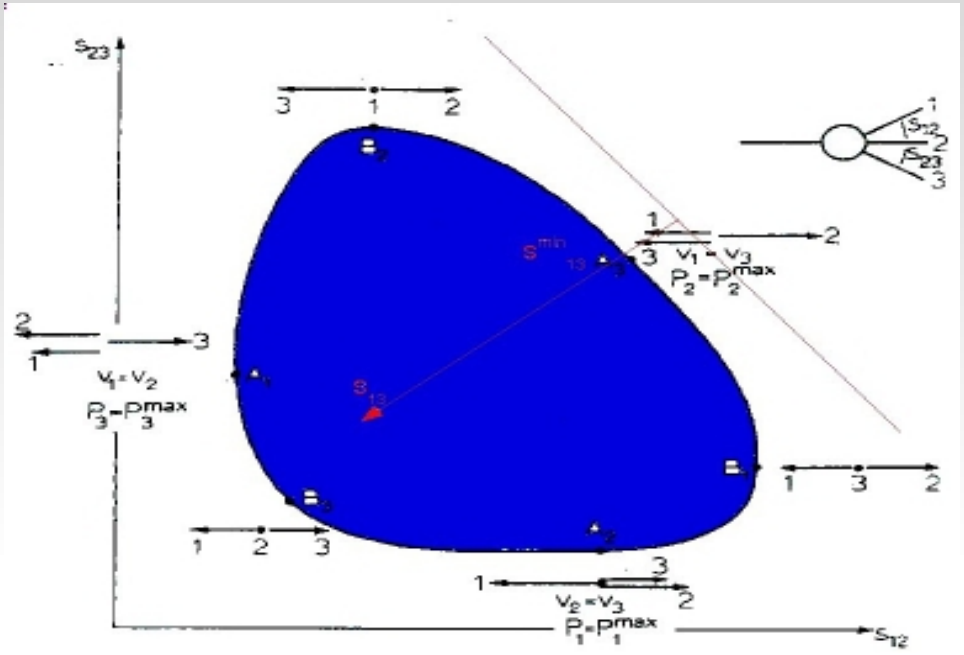
simple counting of events between charge conjugates final states.



$$A_{cp}(B^0 \rightarrow K^+\pi^-) = \frac{|\langle K^+\pi^- | T | B^0\rangle|^2 - |\langle K^-\pi^+ | T | \bar{B}^0\rangle|^2}{|\langle K^+\pi^- | T | B^0\rangle|^2 + |\langle K^-\pi^+ | T | \bar{B}^0\rangle|^2}$$

CP violation in charged heavy meson three body decay

Dalitz Plot-

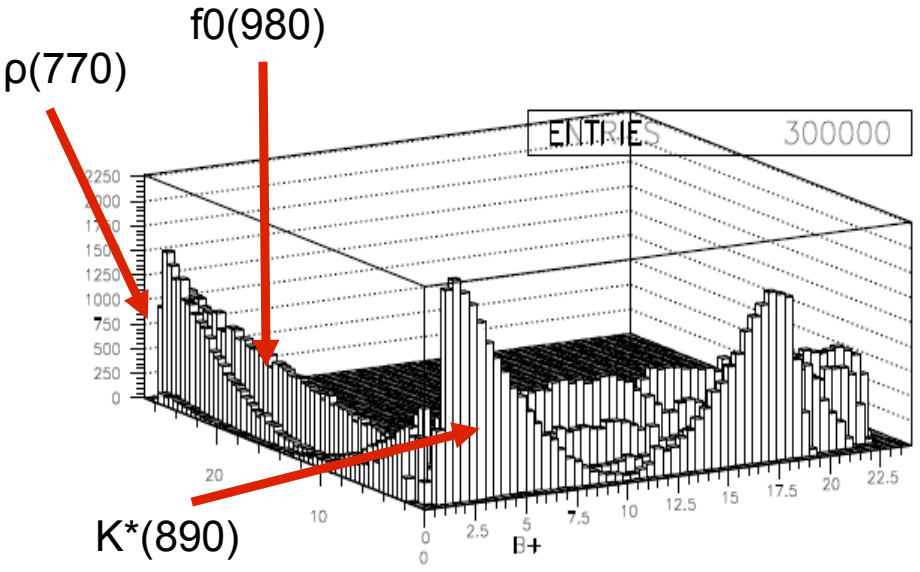


$$s_{12} = M_{12}^2 = (p_1^\nu + p_2^\nu)^2$$
$$s_{13} = M_{13}^2 = (p_1^\nu + p_3^\nu)^2$$
$$s_{23} = M_{23}^2 = (p_2^\nu + p_3^\nu)^2$$

Flat phase space where it is write the dynamics.

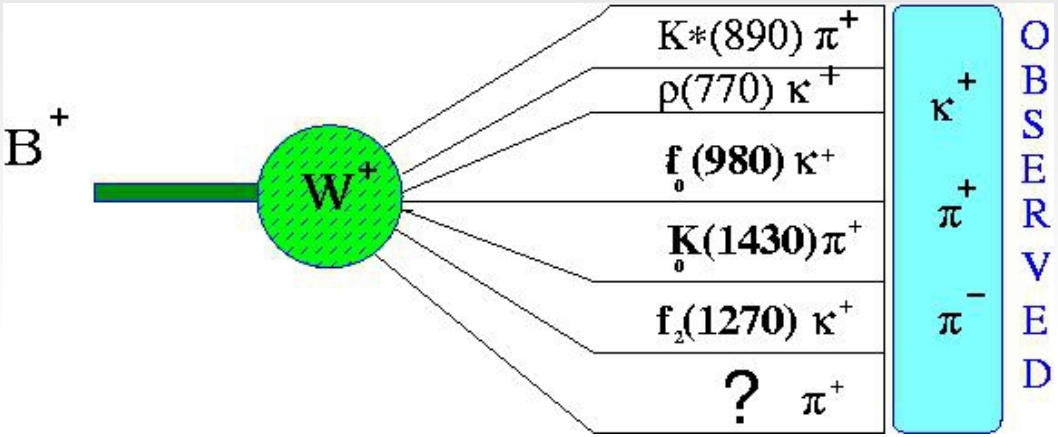
$$d\Gamma(s_{12}, s_{23}) = \frac{1}{(2\pi)^3 32 M_B^3} |\mathcal{M}|^2 \, ds_{12} ds_{23}$$

$$| M |^2 \Rightarrow \textbf{resonances}$$

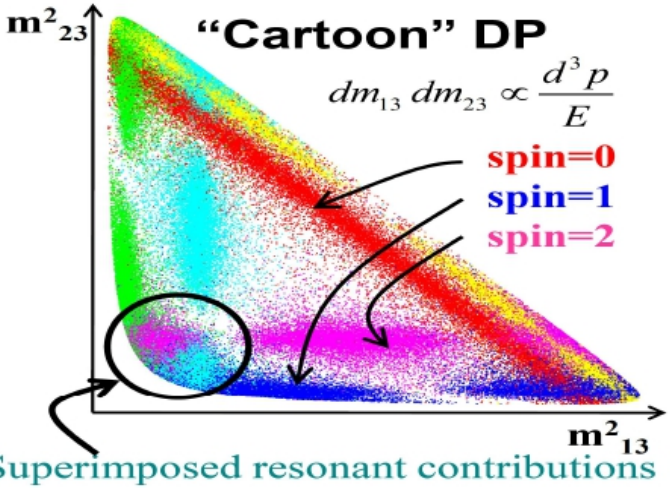


Charmless three body B charge decays

- *Study the B decays and their intermediary states:*



Coherent sum of amplitudes



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

Strong hadronic phases difference between intermediary states.

If they have different weak phases ⇒ in CP violation.

Phases in Dalitz plot

Signature of the phase difference between two interfering resonances

$$|\mathcal{M}|^2 = |a_{\pi^+\pi^-}|^2 + |a_{\pi^+\pi^0}|^2 + 2|a_{\pi^+\pi^-}\ a_{\pi^+\pi^0}|$$

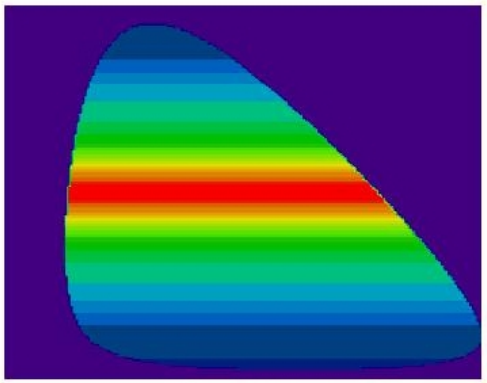


Figure 1: $|a_{\pi^+\pi^-}| = 1, |a_{\pi^+\pi^0}| = 0$

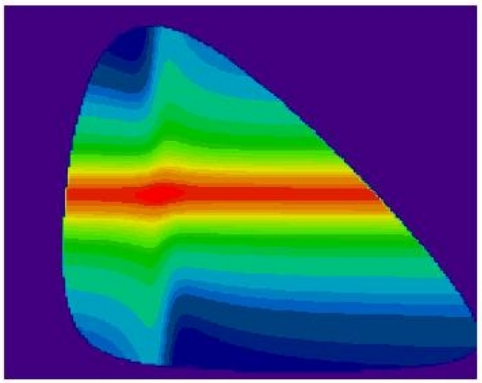


Figure 2: $|a_{\pi^+\pi^-}| = 1, |a_{\pi^+\pi^0}| > 0$

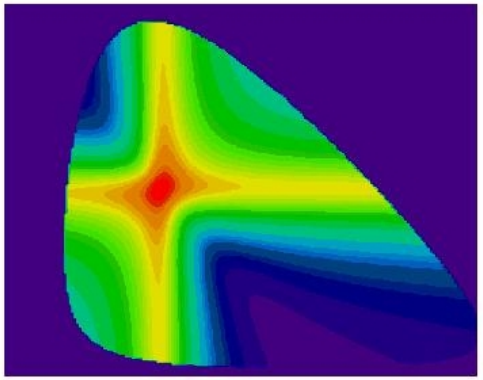


Figure 3: * $|a_{\pi^+\pi^-}| = |a_{\pi^+\pi^0}| = 1, \Delta\Phi = 0^0$

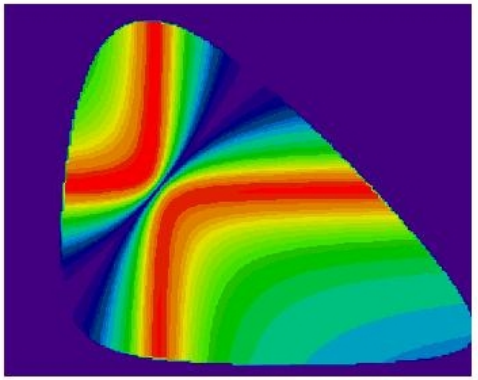


Figure 4: * $|a_{\pi^+\pi^-}| = |a_{\pi^+\pi^0}| = 1, \Delta\Phi = 90^0$

CP violation in three body decays:

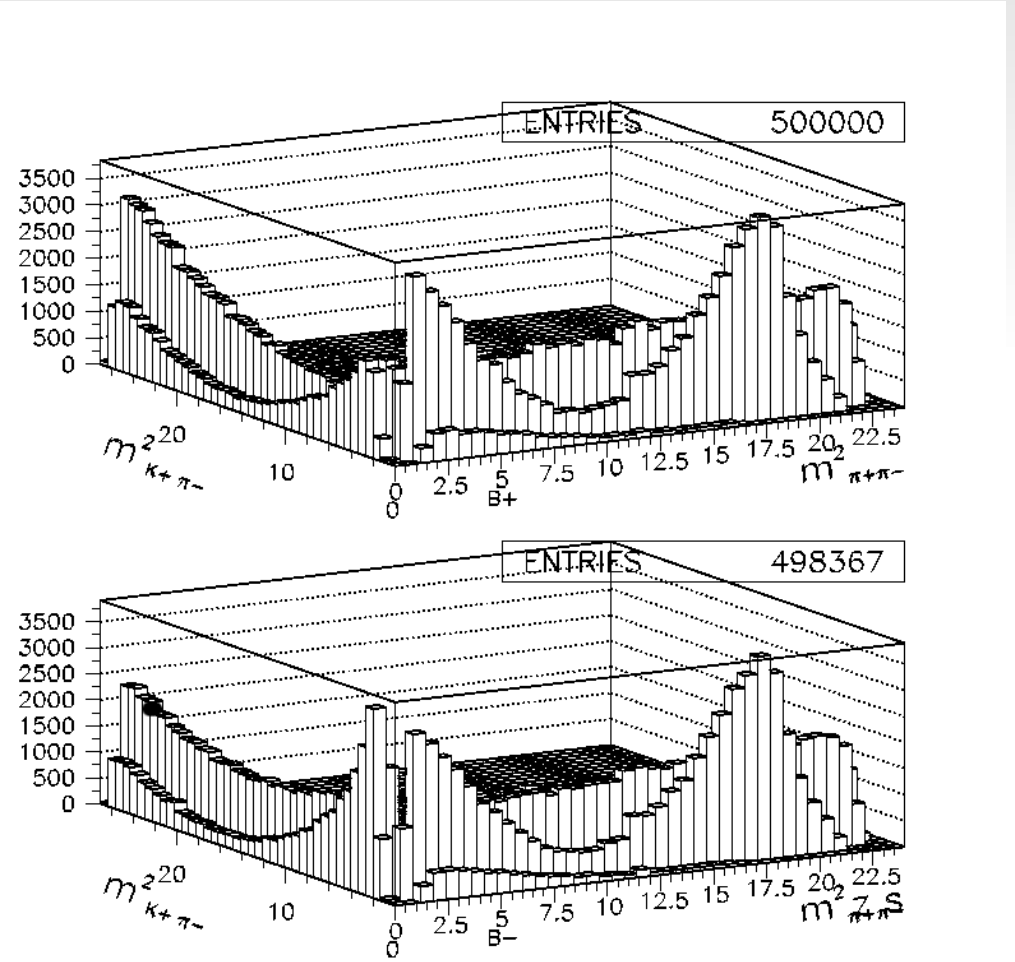
Difference between the two Dalitz plane.

$$\Downarrow$$

$$B^- \rightarrow K^- \pi^+ \pi^-$$

$$\neq$$

$$B^+ \rightarrow K^+ \pi^+ \pi^-$$



Evidence of CP violation in $B \to K\pi\pi$, $B \to KKK$, $B \to \pi\pi\pi$ and $B \to \pi KK$

Final results

with LHCb 2011 +2012 data

Phys.Rev. D90 (2014) 11, 112004

Tom's talk in this seminar

Inclusive result

Tom's talk in this seminar

- CP asymmetries measured in full phase space:

$$A_{CP}(B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = +0.025 \pm 0.004 \pm 0.004 \pm 0.007,$$
$$A_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.036 \pm 0.004 \pm 0.002 \pm 0.007,$$
$$A_{CP}(B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}) = +0.058 \pm 0.008 \pm 0.009 \pm 0.007,$$
$$A_{CP}(B^{\pm} \to \pi^{\pm}K^{+}K^{-}) = -0.123 \pm 0.017 \pm 0.012 \pm 0.007,$$

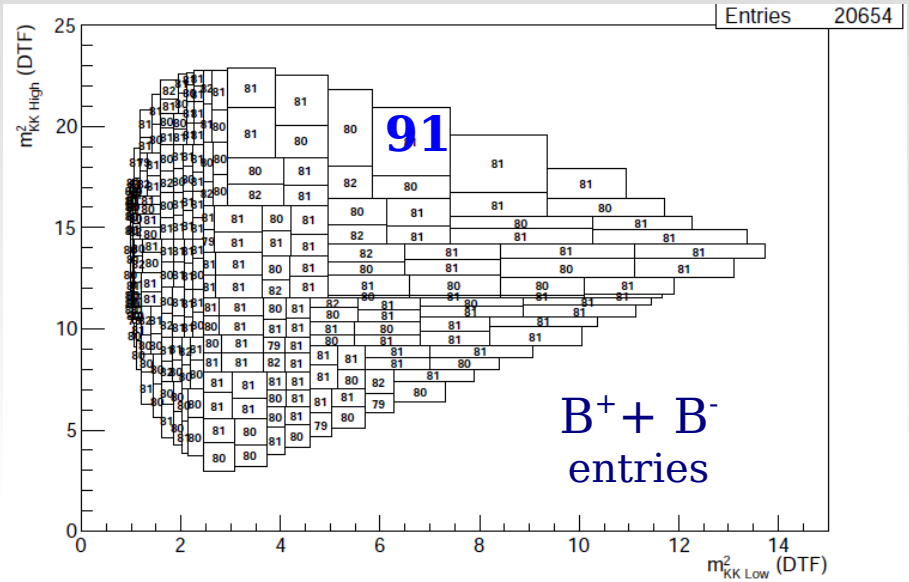
LHCb 2011 +2012 data

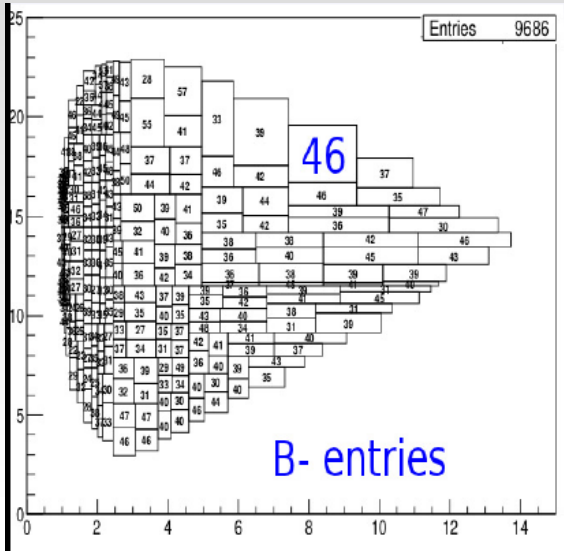
Phys.Rev. D90 (2014) 11, 112004

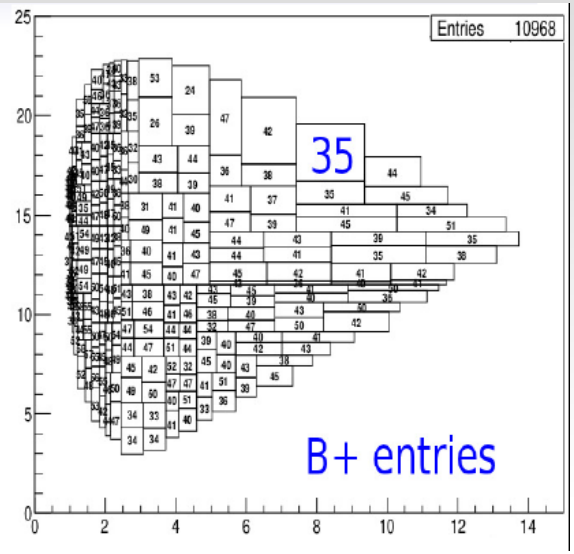
Tom's talk in this seminar

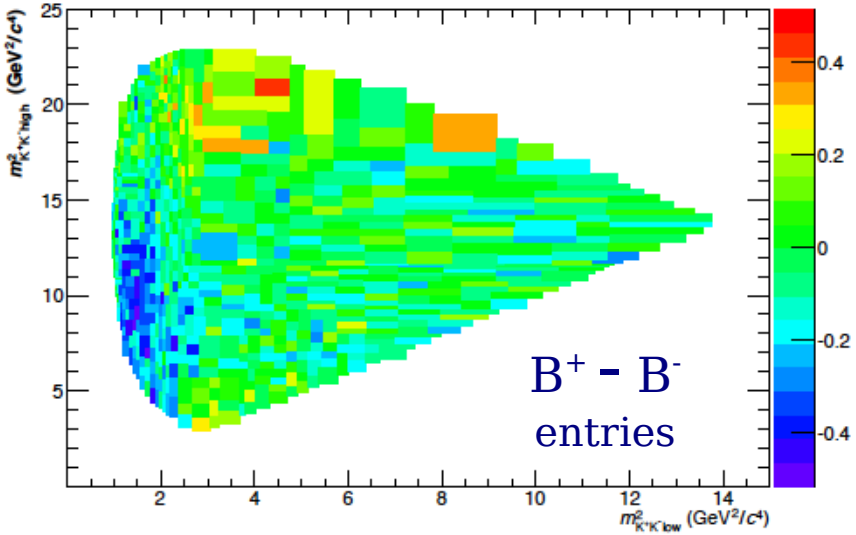
B^+ - B^- Dalitz differences

M^2_{K+K-} Vs M^2_{K+K-} phase space distribution









Simetrical Dalitz

If $M^2_{K+K1-} > M^2_{K+K2-}$

$M^2_{K+K1-} = M^2_{K+K-high}$

and

$M^2_{K+K1-} = M^2_{K+K-low}$

Otherwise .....

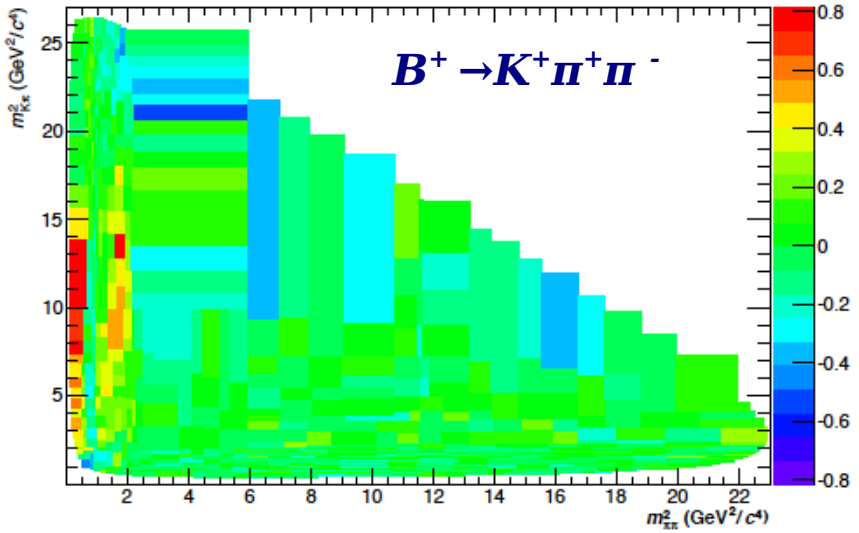
PHYSICAL REVIEW D 90, 112004 (2014)

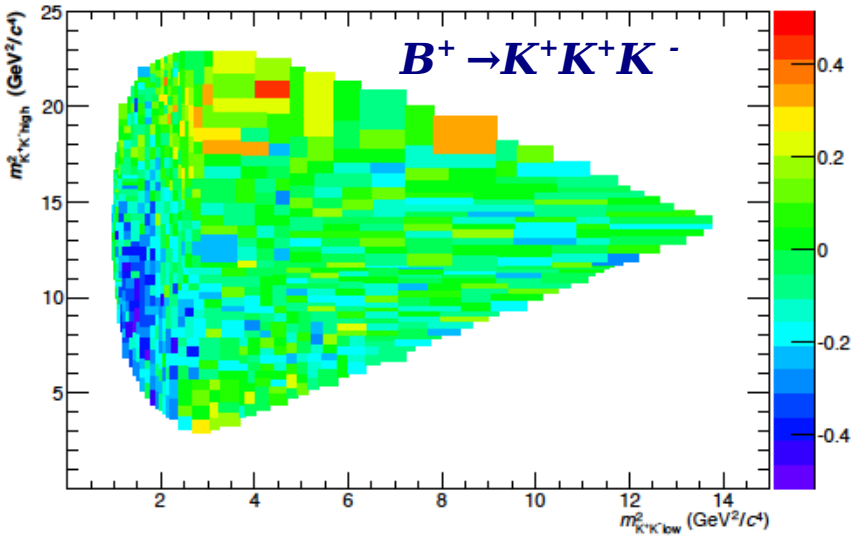
Measurements of *CP* violation in the three-body phase space of charmless $B^{\pm}$ decays

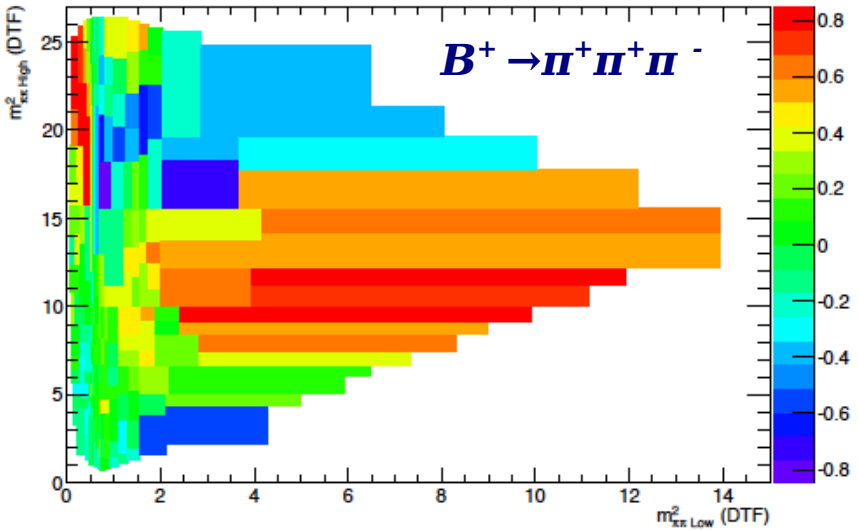
R. Aaij *et al.*[*]
(LHCb Collaboration)

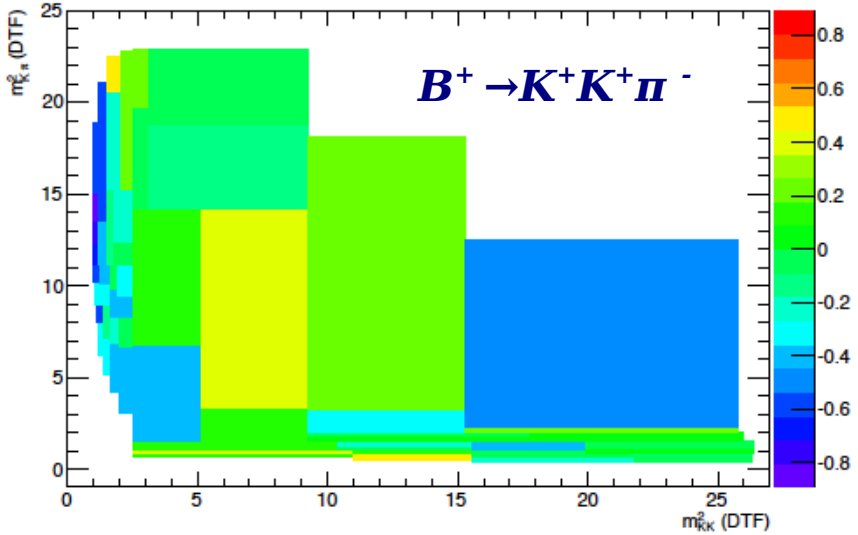
TABLE I. Signal yields of charmless three-body $B^{\pm}$ decays for the full data set.

Decay mode	Yield
$B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$	181074 ± 556
$B^{\pm} \to K^{\pm}K^{+}K^{-}$	109240 ± 354
$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$	24907 ± 222
$B^{\pm} \to \pi^{\pm}K^{+}K^{-}$	6161 ± 172



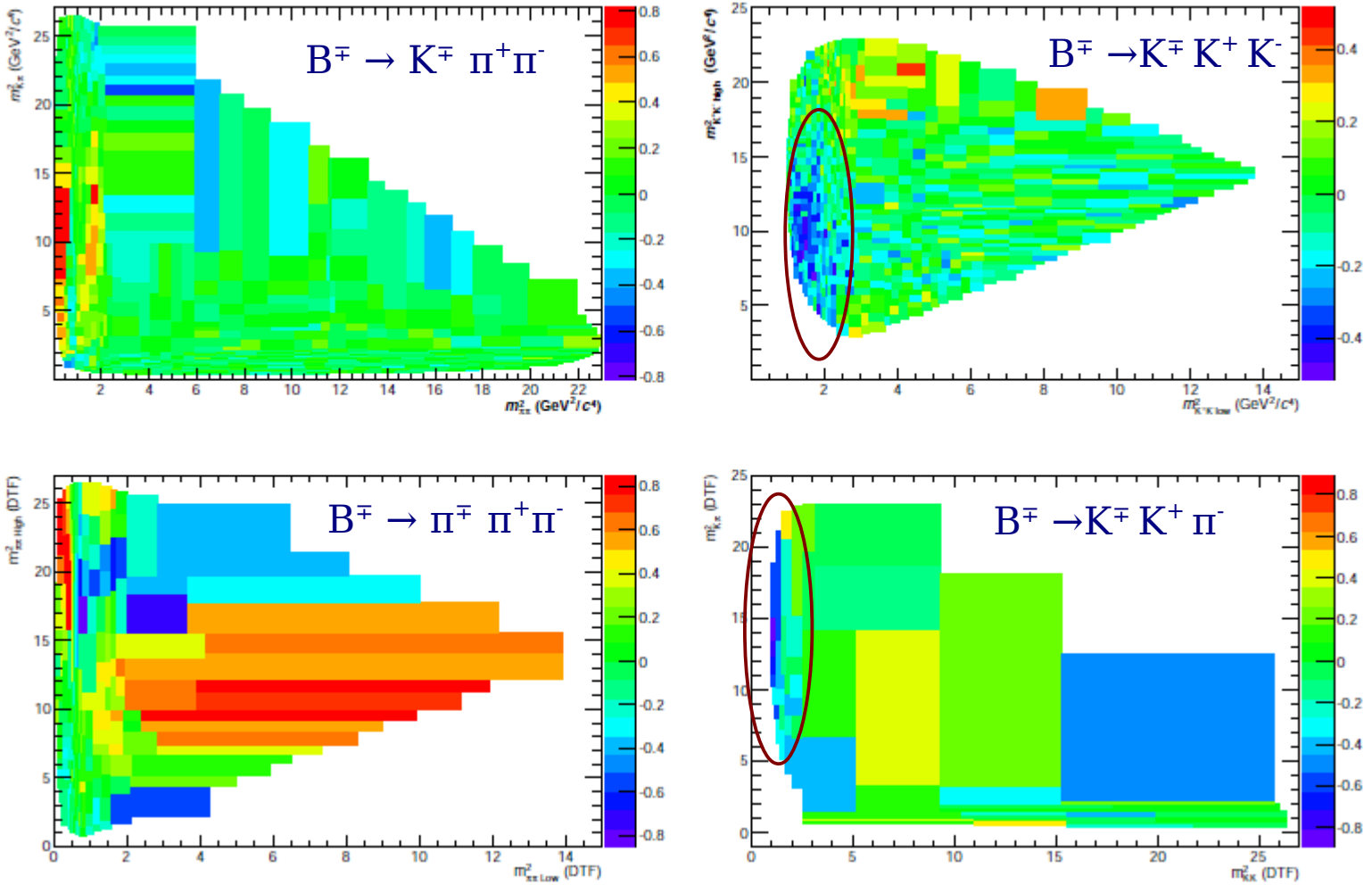






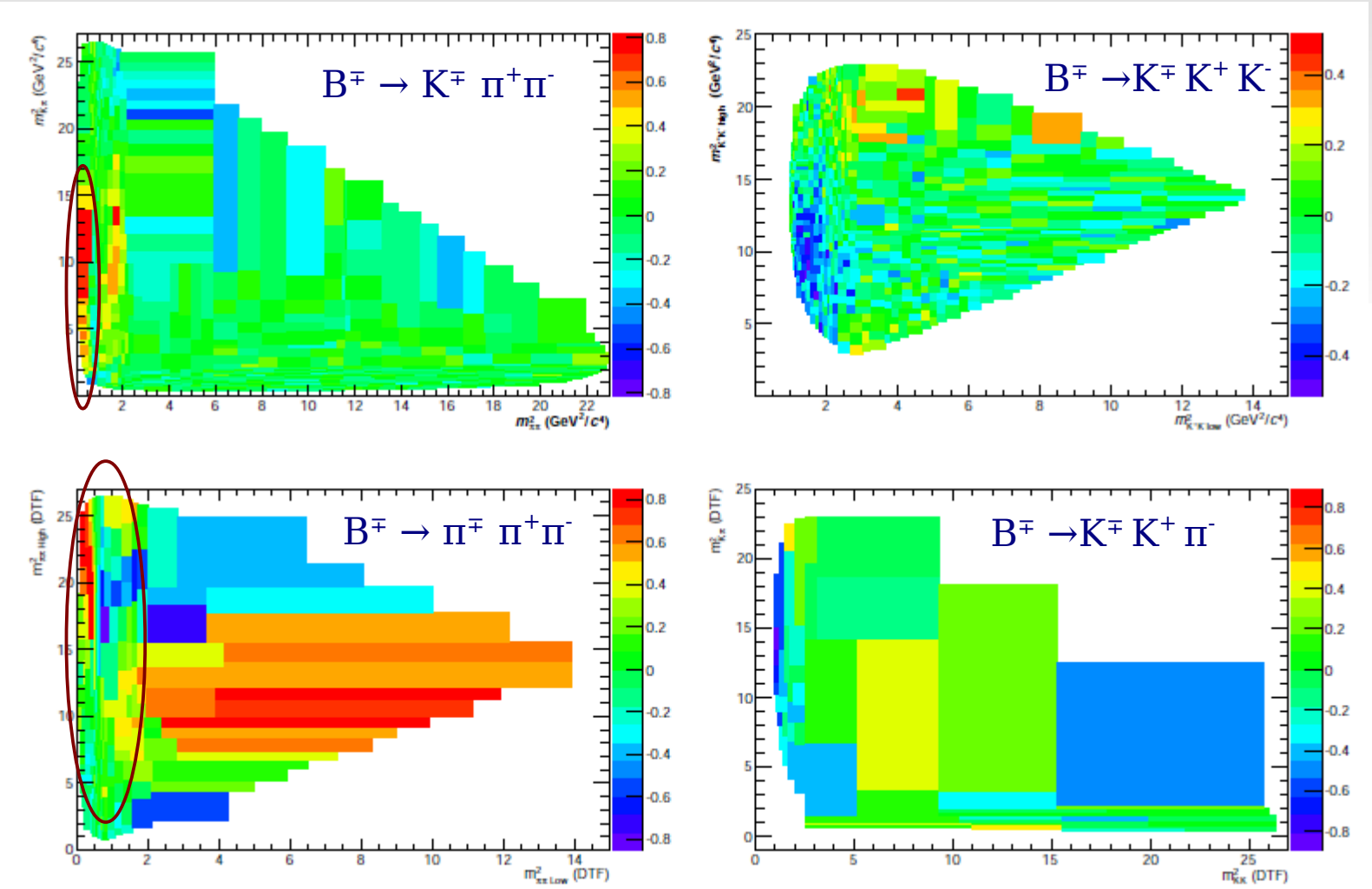
CP Dalitz distribution for the four $B^{\mp} \to h^{\mp} h^{+} h^{-}$ channels

1- Final state interaction $\pi^{+}\pi^{-} \to K^{+}K^{-}$



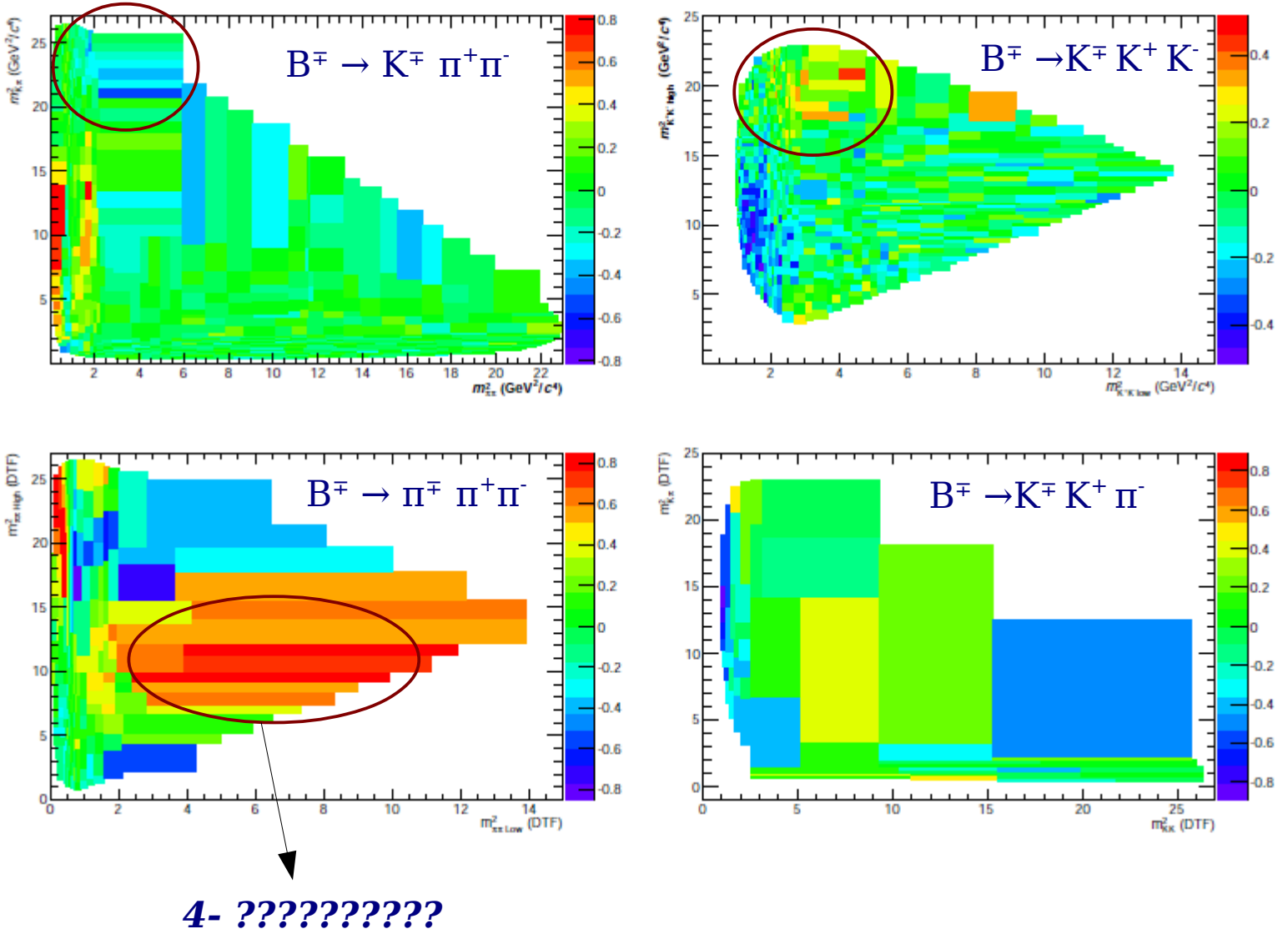
CP Dalitz distribution for the four $B^{\mp} \to h^{\mp} h^{+} h^{-}$ channels

2- $\pi^{+}\pi^{-} \to$ S and P wave interaction



CP Dalitz distribution for the four $B^{\mp} \to h^{\mp} h^{+} h^{-}$ channels

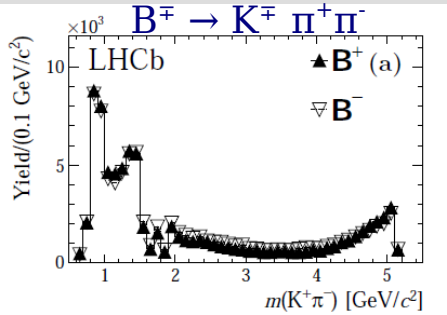
3- $h^{+} h^{-} \to D^{+} D^{-}$ as thinking as a possibility by Wolfenstein

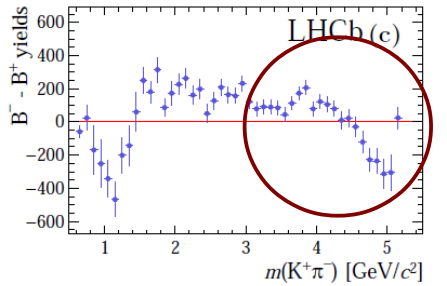


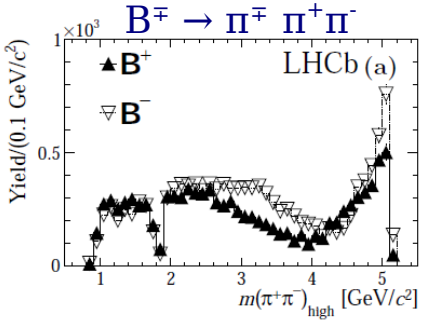
4- ??????????

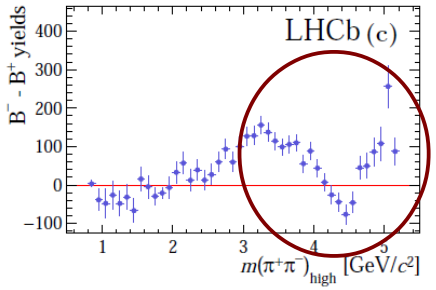
CP Dalitz asymmetry for high mass for the four $B^{\mp} \to h^{\mp} h^{+} h^{-}$ channels

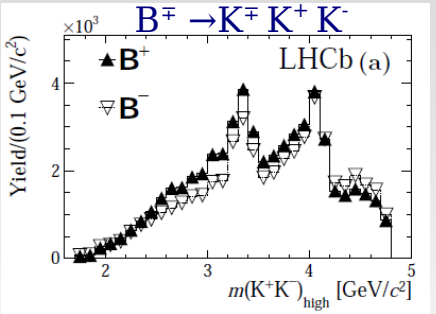
New LHCb results: available at https://cds.cern.ch/record/1751517?ln=en

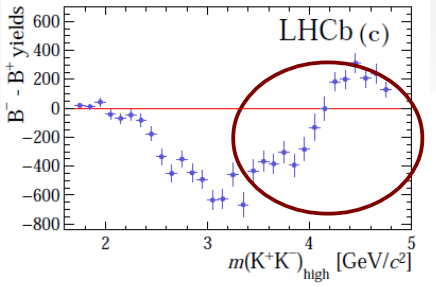


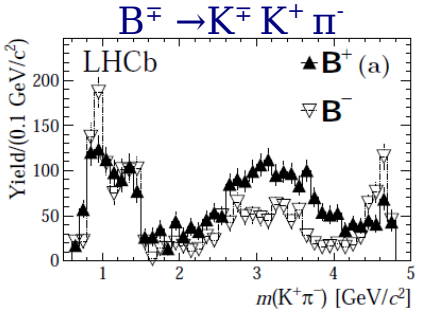


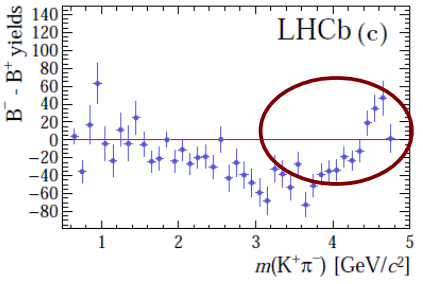








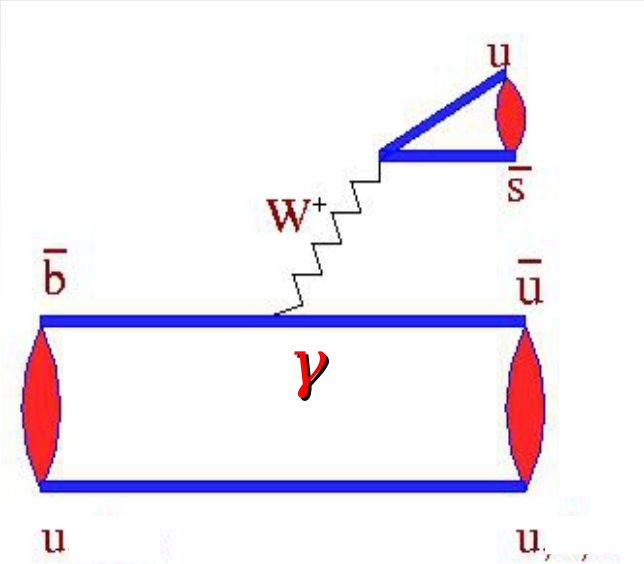


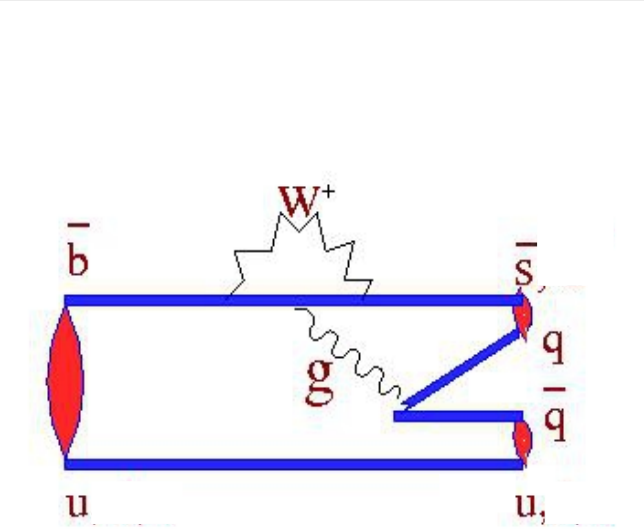


CP violation through $\pi^+\pi^- \to K^+K^-$ final state interaction

Parton amplitude to $B^{\mp} \rightarrow K^{\mp} \pi^{+} \pi^{-}$ and $B^{\mp} \rightarrow K^{\mp} K^{+} K^{-}$ Decays

Strangness -1





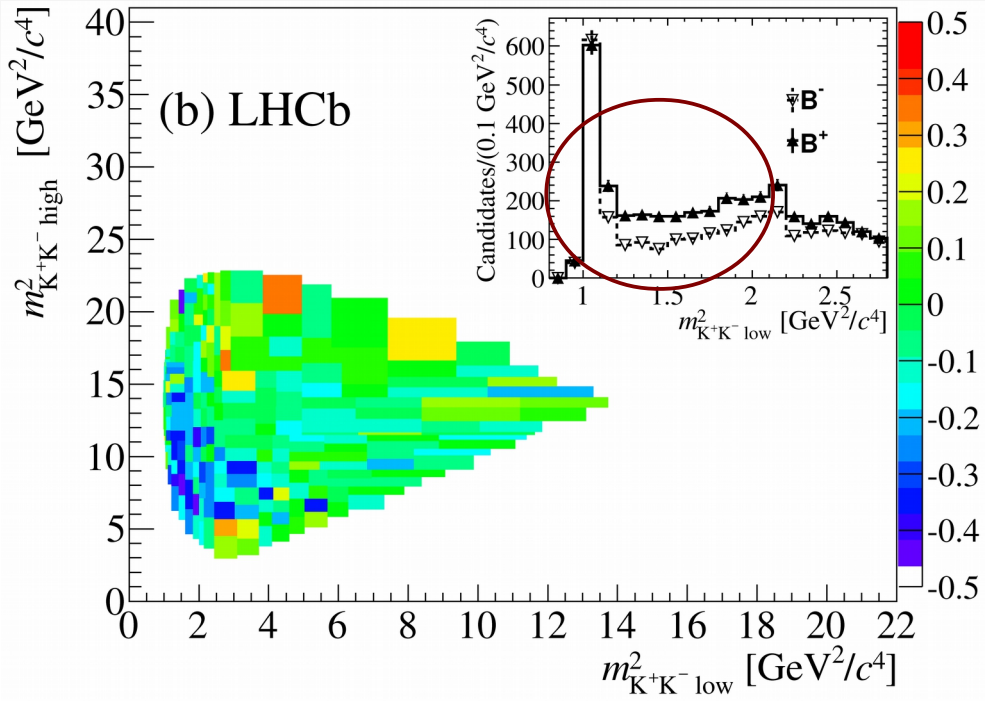
Final state with $\pi^{+} \pi^{-}$ or $K^{+} K^{-}$

B^+ - B^- Dalitz differences

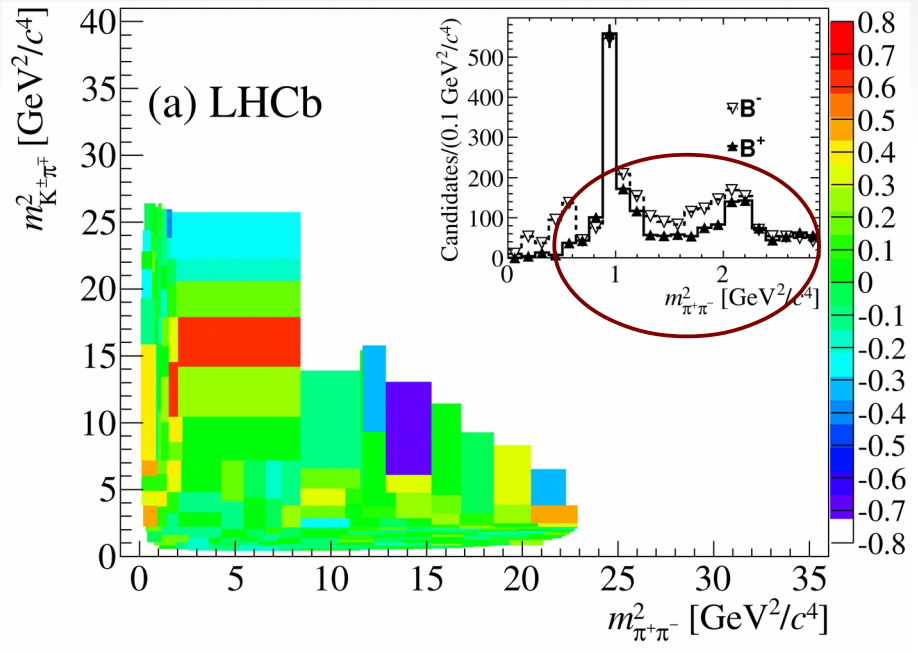
2011 data

LHCb: PRL 111, 101801 (2013)

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

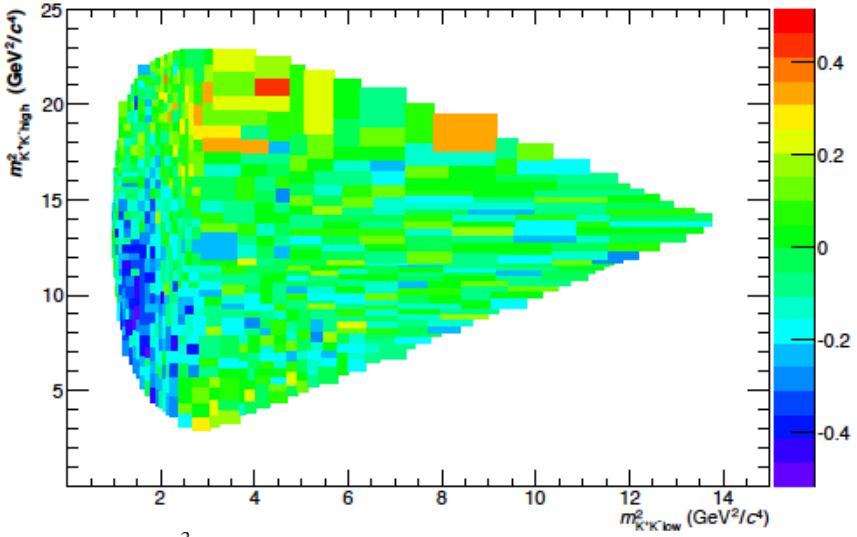


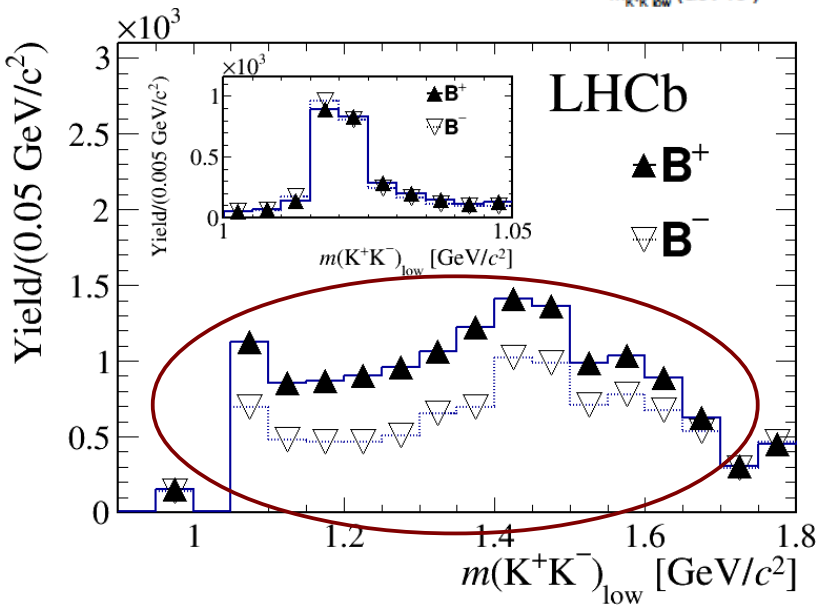
$B^\mp \to K^\mp \pi^+ \pi^-$



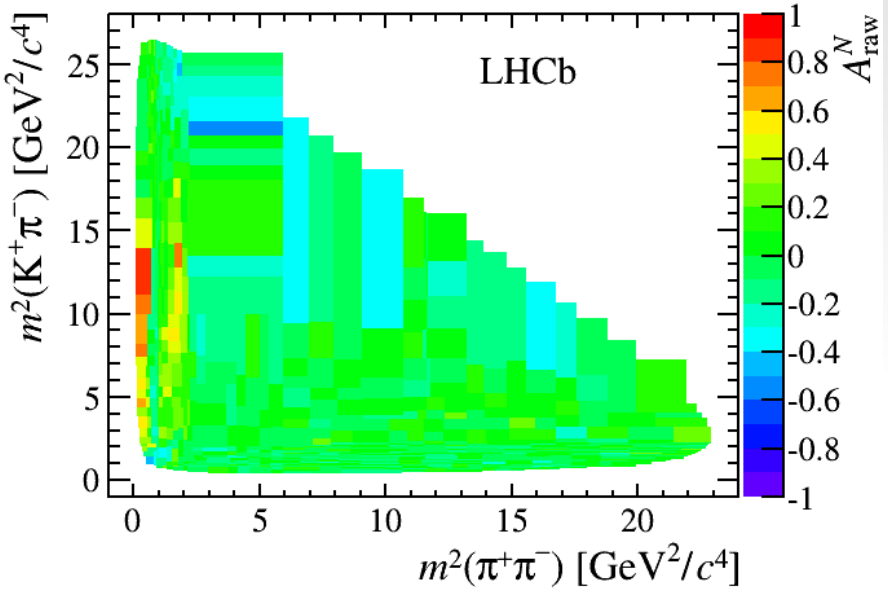
B^+ - B^- Dalitz differences
phase space distribution 2011 + 2012 data

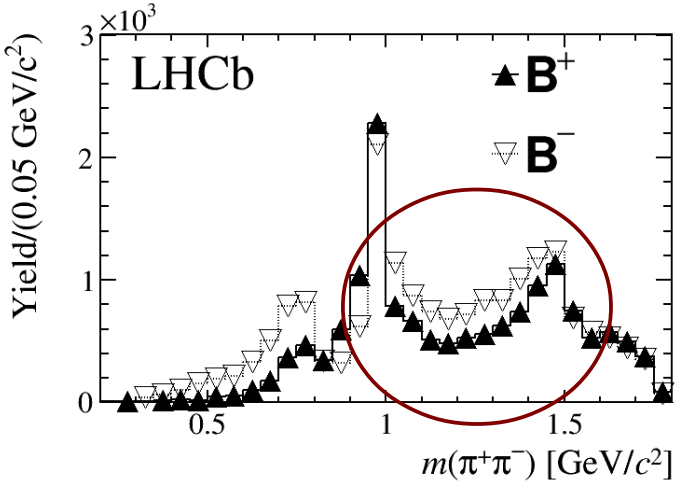
$B^\mp \to K^\mp K^+ K^-$





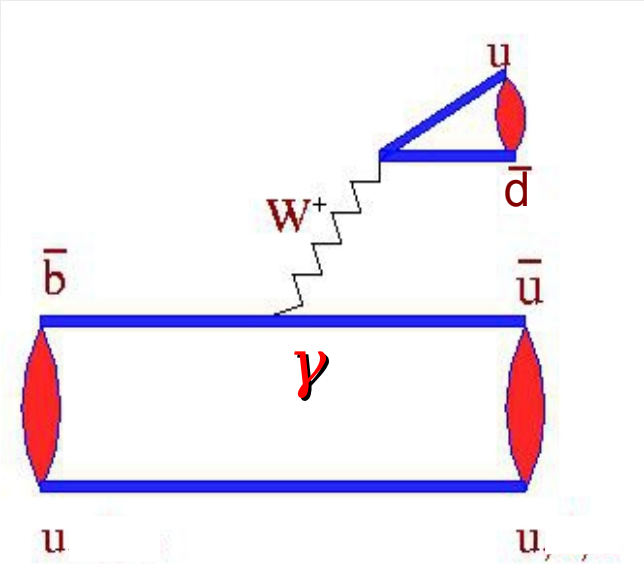
$B^\mp \to K^\mp \pi^+ \pi^-$

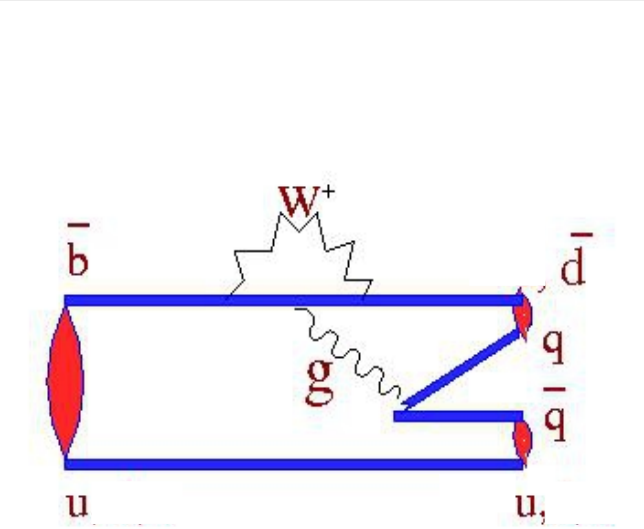




Parton amplitude to $B^{\mp} \rightarrow K^{\mp} K^{+} \pi^{-}$ and $B^{\mp} \rightarrow \pi^{\mp} \pi^{+} \pi^{-}$ Decays

Strangness - 0

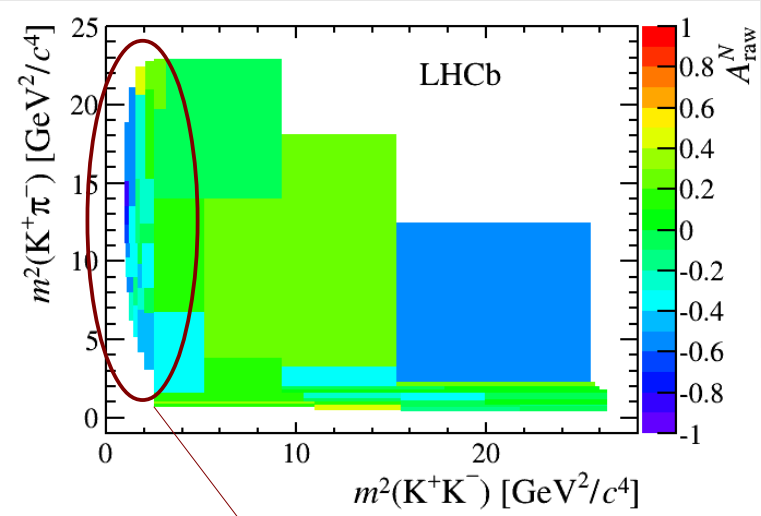


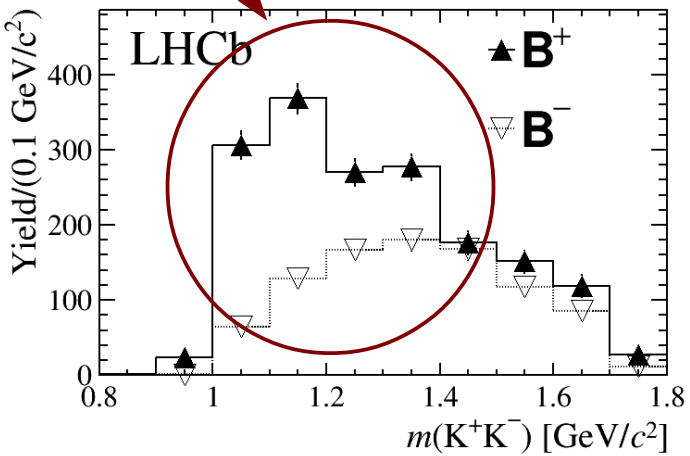


Final state with $\pi^{+} \pi^{-}$ or $K^{+} K^{-}$

B^+ - B^- Dalitz differences
phase space distribution 2011 + 2012 data

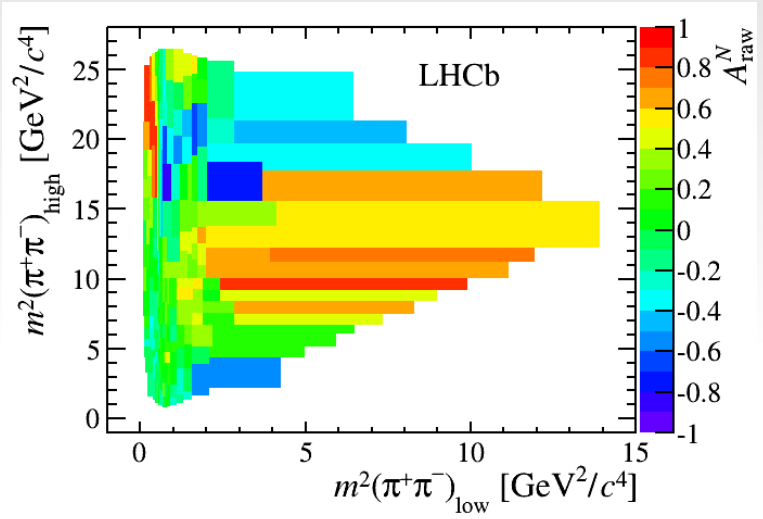
$B^{\mp} \rightarrow \pi^{\mp} K^+ K^-$

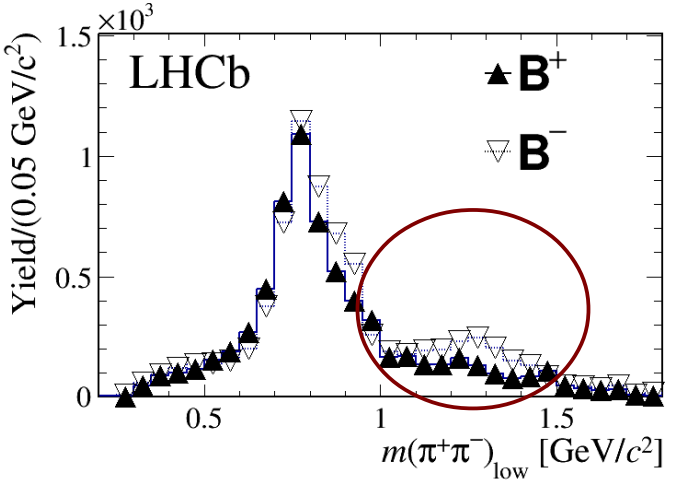




ACP ~ 33%

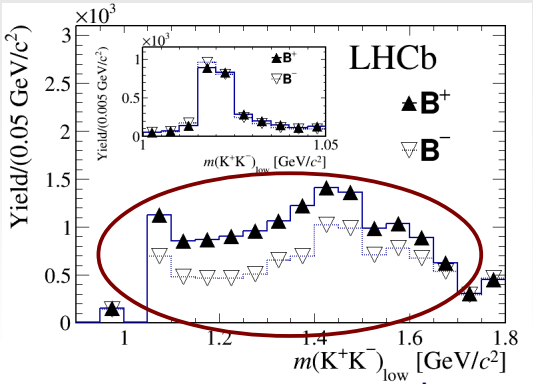
$B^{\mp} \rightarrow \pi^{\mp} \pi^+ \pi^-$



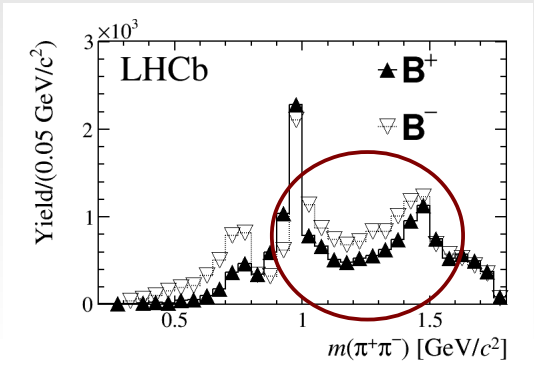


Remarks of the experimental results: *final state interaction $\pi^+\pi^- \to K^+K^-$*

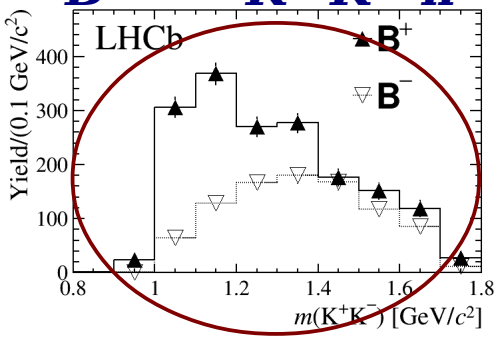
$B^\mp \to K^\mp K^+ K^-$



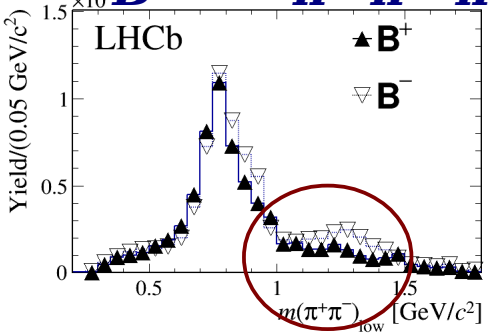
$B^\mp \to K^\mp \pi^+ \pi^-$



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



$B^\mp \to \pi^\mp \pi^+ \pi^-$



- Global CP observed in all 4 channels
- positive CP in $B^\mp \to K^\mp \pi^+ \pi^-$ and $B^\mp \to \pi^\mp \pi^+ \pi^-$
- negative in $B^\mp \to \pi^\mp K^+ K^-$ and $B^\mp \to K^\mp K^+ K^-$
- Similar amount of events involving CP asymmetry in the same K^+K^- and $\pi^+\pi^-$ invariant mass regions.

CPT constraint for direct CP asymmetry,

CPT Invariance

- *CPT invariance ⇒ Same lifetime and same mass to particle and anti-particle.*

$$\text{Lifetime} \quad \tau = 1 / \Gamma_{total} = 1 / \overline{\Gamma}_{total}$$

$$\Gamma_{total} = \Gamma_1 + \Gamma_2 + \Gamma_3 + \Gamma_4 + \Gamma_5 + \Gamma_6 + \ldots\ldots\ldots\ldots$$

$$\overline{\Gamma}_{total} = \overline{\Gamma}_1 + \overline{\Gamma}_2 + \overline{\Gamma}_3 + \overline{\Gamma}_4 + \overline{\Gamma}_5 + \overline{\Gamma}_6 + \ldots\ldots\ldots\ldots$$

- ~~CP~~ violation $\Rightarrow \Gamma_1 > \overline{\Gamma}_1$.
- CPT conservation:

$$\Gamma_2 + \Gamma_3 + \Gamma_4 + \Gamma_5 + \Gamma_6 + \ldots\ldots\ldots < \overline{\Gamma}_2 + \overline{\Gamma}_3 + \overline{\Gamma}_4 + \overline{\Gamma}_5 + \overline{\Gamma}_6 + \ldots\ldots\ldots\ldots$$

In a exact proportion.

- It is necessary to include final state interaction in the CP violation calculation.

Direct CP violation charged particles:

Different disintegration behavior from particle and anti-particle

Two contribution to a same final state.

With different strong phases (δ_1 and δ_2) and weak phases (ϕ_1 and ϕ_2).

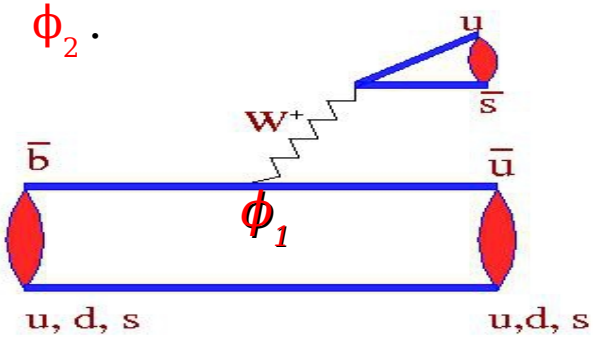
$$A(B \to f) = A_1 e^{i\phi_1} e^{i\delta_1} + A_2 e^{i\phi_2} e^{i\delta_2} ,$$
$$A(\bar{B} \to \bar{f}) = A_1 e^{-i\phi_1} e^{i\delta_1} + A_2 e^{-i\phi_2} e^{i\delta_2} .$$

CP Violation:
Datta presentation

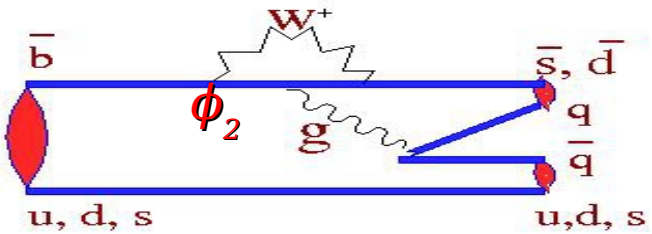
Γ (i→f) - Γ ($\bar{i}$→$\bar{f}$) =

$$|\langle f|T|i\rangle|^2 - |\langle \bar{f}|T|\bar{i}\rangle|^2 = -4A_1A_2 \sin(\delta_1 - \delta_2)\sin(\phi_1 - \phi_2)$$

So CP Violation needs: different strong δ_1 and δ_2 and weak phases ϕ_1 and ϕ_2 .



Interference=>CP



Short distance: BSS Model Bander Silverman and Soni PRL 43 (1979) 242

This formulation is at least incomplete

The common believe: *Ikaros Bigi hep-ph 1503-07719*

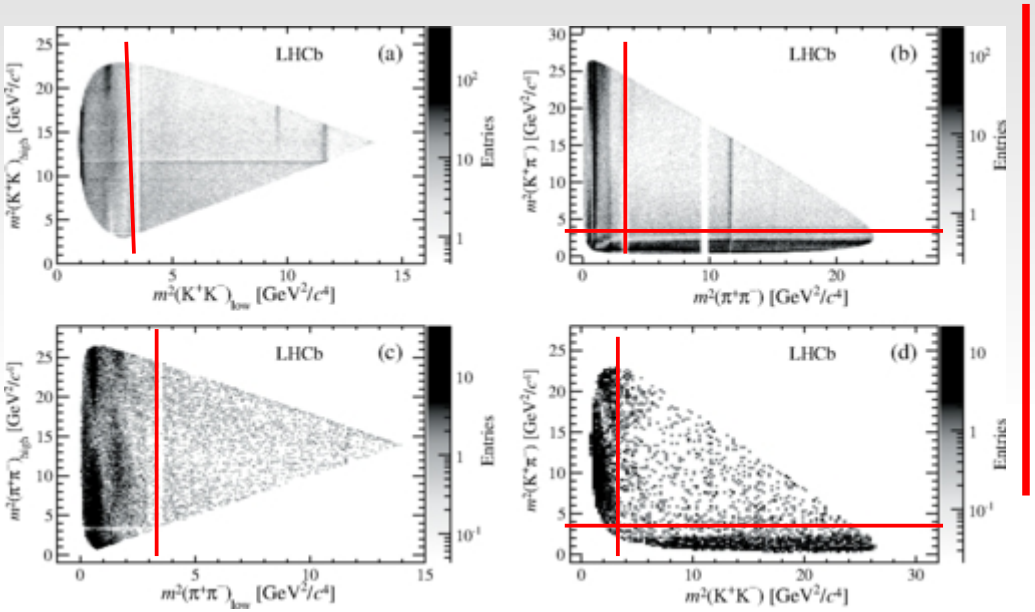
' The CKM suppressed weak decays for beauty hadrons produce FS with more hadrons than two, three & four ones. Therefore one expects that CPT invariance is not a “practical“ tool in *beauty decays* '

For ex. the $B^+ \to K^+ \pi^+ \pi^-$ can have many B decay channels with accessible FSI

- $B^+ \to K^0 \pi^+$
- $B^+ \to K^+ \pi^0$
- $B^+ \to K^+ \eta$
- $B^+ \to K^0 \pi^+ \pi^0$
- $B^+ \to K^+ K^0 K^0$
- $B^+ \to K^+ K^+ K^-$
- $B^+ \to K^0 \pi^+ \eta^0$
- $B^+ \to K^+ \pi^0 \eta^0$
- *Plus 4 bodys*

Has really hadronic interaction many degrees of freedom ???

$B^{\mp} \to h^{\mp} h^{+} h^{-}$ events distribution.



- ***More than 90% of the events has $M^2_{h+h^-} < 3.0 GeV^2$ supporting the general idea of 2+1 first order approximation.***

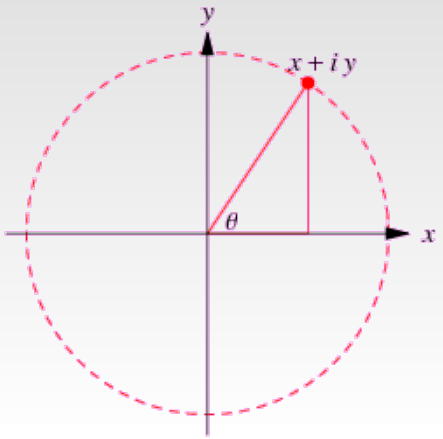
- ***Similar theoretical conclusion in the recent paper:***
  "Three-body non-leptonic B decays and QCD factorization" from S. Kränkl, Thomas Mannel and Javier Virto- N.P. B899 (2015) 247.

With this approximation → to the FSI we can use elements of elastic scattering

Elastic scattering: $K^+\pi^- \to K^+\pi^-$

Inelasticity: $\eta = 1 \Rightarrow$ 100% of hh going hh,
$\eta = 0 \Rightarrow$ 0% going to other final states.

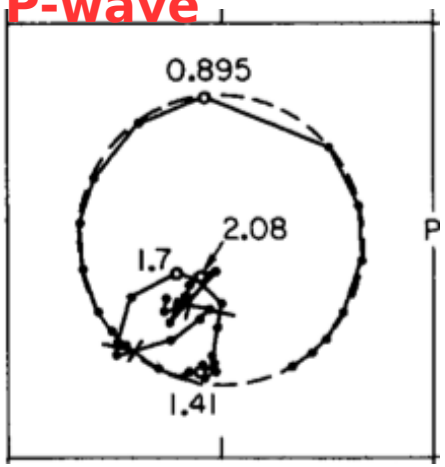
Argand circle.



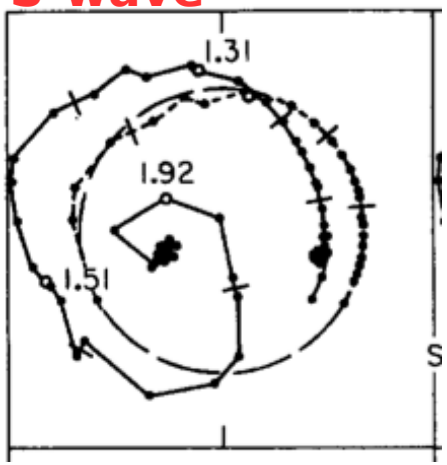
LASS collaboration $K^+\pi^- \to K^+\pi^-$ (1988)

Nuclear Physics B296 (1988) 493–526

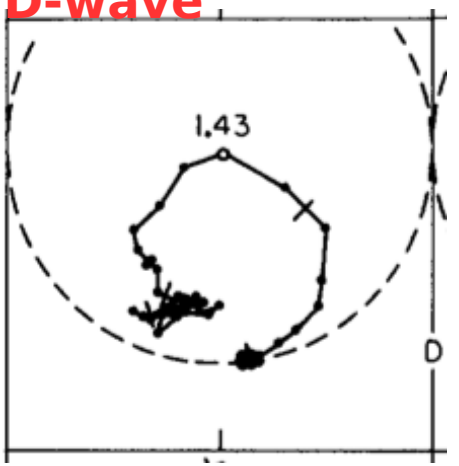
P-wave



S-wave



D-wave



No deviation of the unitary circle to P-wave till 1.6GeV.
S-wave is also in the unitary circle, if one exclude I=3/2 contribution.

Elastic scattering $\pi^+\pi^- \to \pi^+\pi^-$.

CERN-Munich collaboration $\pi^+\pi^- \to \pi^+\pi^-$ (1973)

Nuclear Physics B64 (1973) 134–162.

S-wave **D-wave**

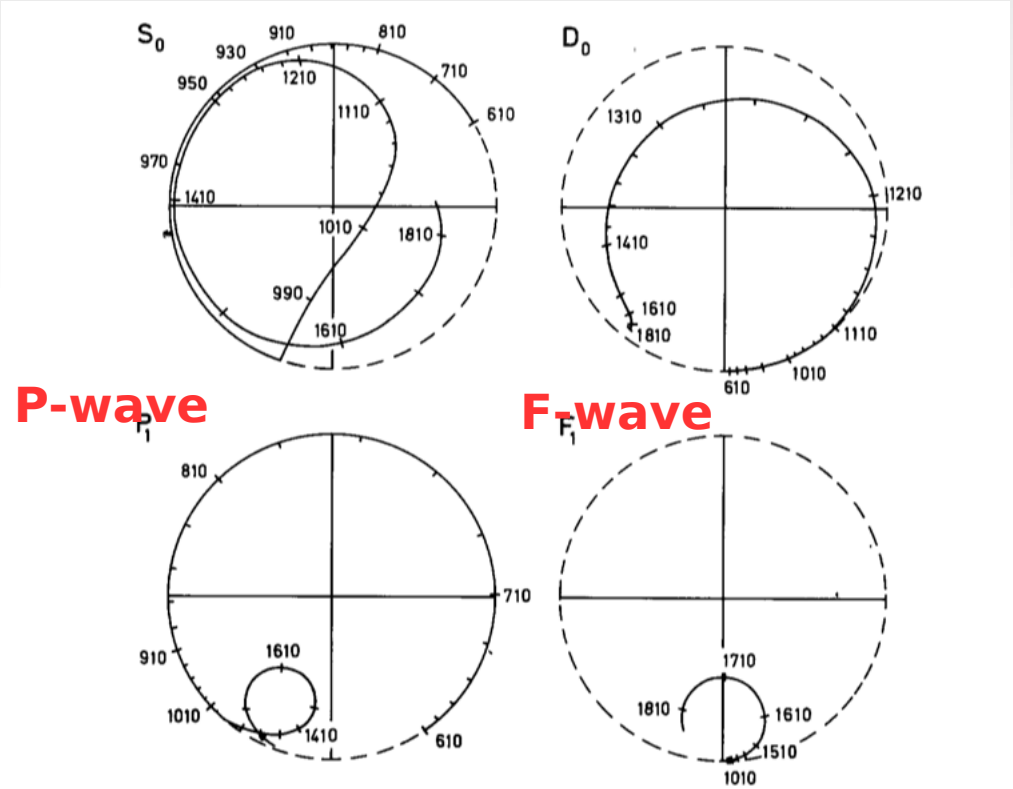


Fig. 6. Argand diagrams (Im T_l^I *versus* Re T_l^I) for the partial wave amplitudes from the energy-dependent fit. Numbers indicate the $\pi\pi$ energy.

P-wave **F-wave**

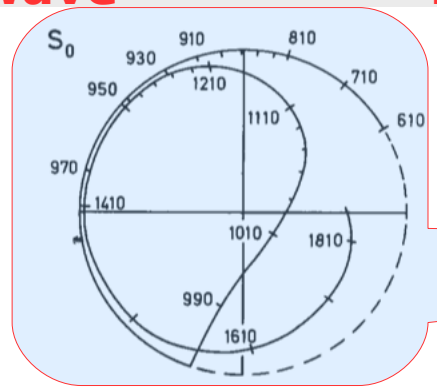
Big deviation of the unitary circle in the S wave between 1 to 1.5GeV.

Elastic scattering $\pi^+\pi^- \to \pi^+\pi^-$.

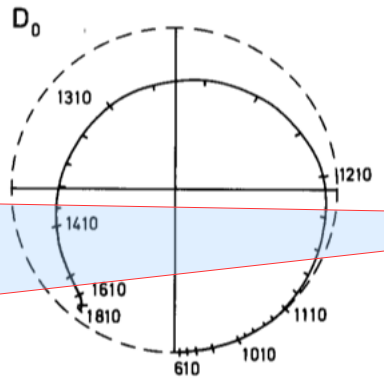
CERN-Munich collaboration $\pi^+\pi^- \to \pi^+\pi^-$ (1973)

Nuclear Physics B64 (1973) 134–162.

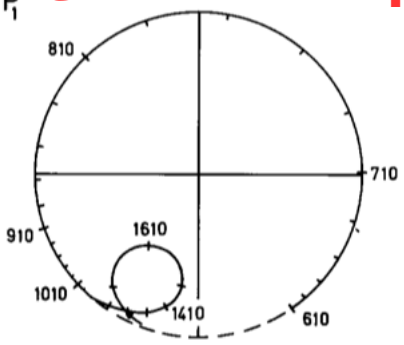
S-wave



D-wave



P-wave



F-wave

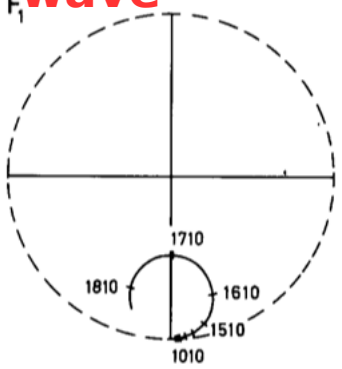


Fig. 6. Argand diagrams (Im T_l^I *versus* Re T_l^I) for the partial wave amplitudes from the energy-dependent fit. Numbers indicate the $\pi\pi$ energy.

Cohen, D et al PRD 22 (1980) 2595

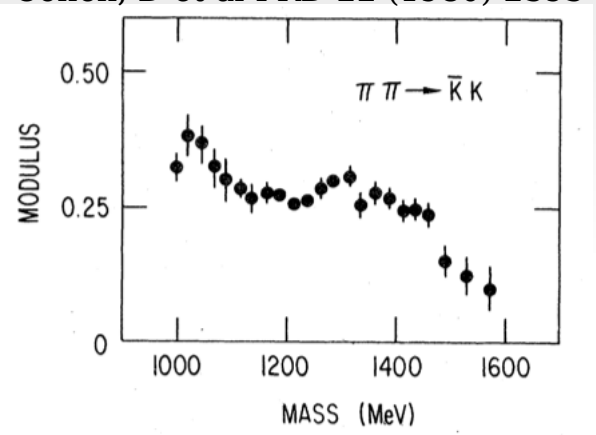


FIG. 27. Modulus of the $\pi\pi \to \overline{K}K$ scattering amplitude $|T(\pi\pi \quad \overline{K}K)|$ from solution I(b).

Strong coupling:

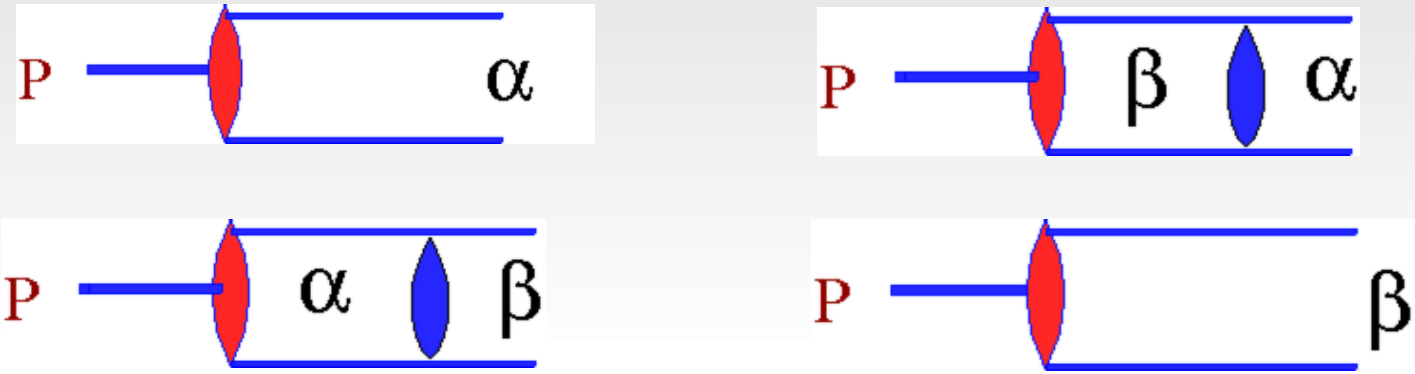
$$\pi^+\pi^- \to K^+K^-$$

Big deviation of the unitary circle in the S wave between 1 to 1.5GeV.

CP violation through a strong phase from hadronic re-scattering.

Wolfenstein (**Phys.Rev. D43 (1991) 151-156)**

In a simplified formulation: P particle decay in a family of only two final states **α** e **β**



$$S = \begin{pmatrix} e^{i2\delta\alpha} & t_{\alpha\beta} e^{i(\delta\alpha+\delta\beta)} \\ t_{\alpha\beta} e^{i(\delta\alpha+\delta\beta)} & e^{i2\delta\beta} \end{pmatrix} \Rightarrow$$

$$\langle \alpha | T | P \rangle = e^{i\delta\alpha} [\, T_\alpha + i t_{\alpha\beta} T_\beta]$$

$$\langle \beta | T | P \rangle = e^{i\delta\beta} [\, T_\beta + i t_{\alpha\beta} T_\alpha]$$

To replacement of P by $\overline{P}$ correspond to changing T_i to T_i^*.

The subtracted square amplitudes is given by:

$$\Delta\alpha = |\langle \alpha | T | P \rangle|^2 - |\langle \overline{\alpha} | T | \overline{P} \rangle|^2 = 4\, \mathrm{Im}\, T^*_\alpha T_\beta$$

$$\Delta\beta = |\langle \beta | T | P \rangle|^2 - |\langle \overline{\beta} | T | \overline{P} \rangle|^2 = -4\, \mathrm{Im}\, T^*_\alpha T_\beta$$

Satisfying CPT:

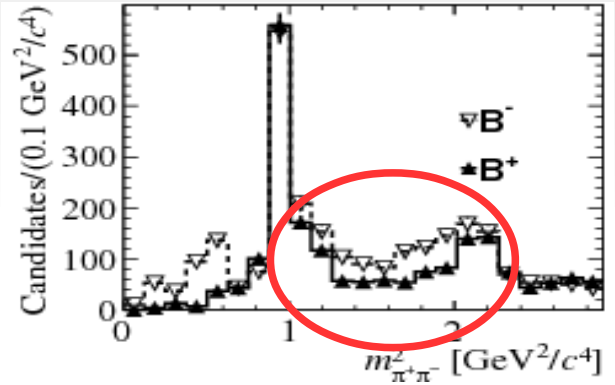
$$\Delta\alpha + \Delta\beta = 0$$

Scattering $\pi^+\pi^- \to K^+K^-$ and CP violation $B^+ \to K^+\pi^+\pi^-$ e $B^+ \to K^+K^+K^-$.

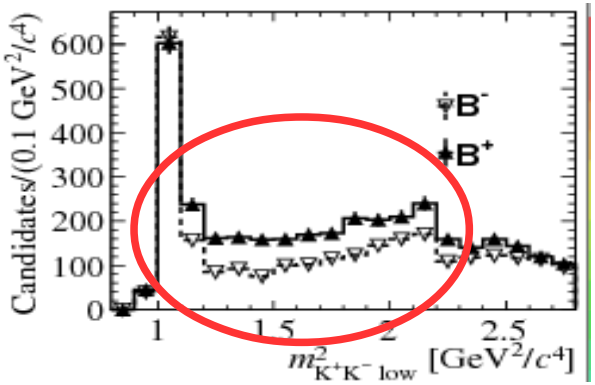
I. B., T. Frederico and O. Lourenço Phys. Rev. D 89, 094013 (2014)-

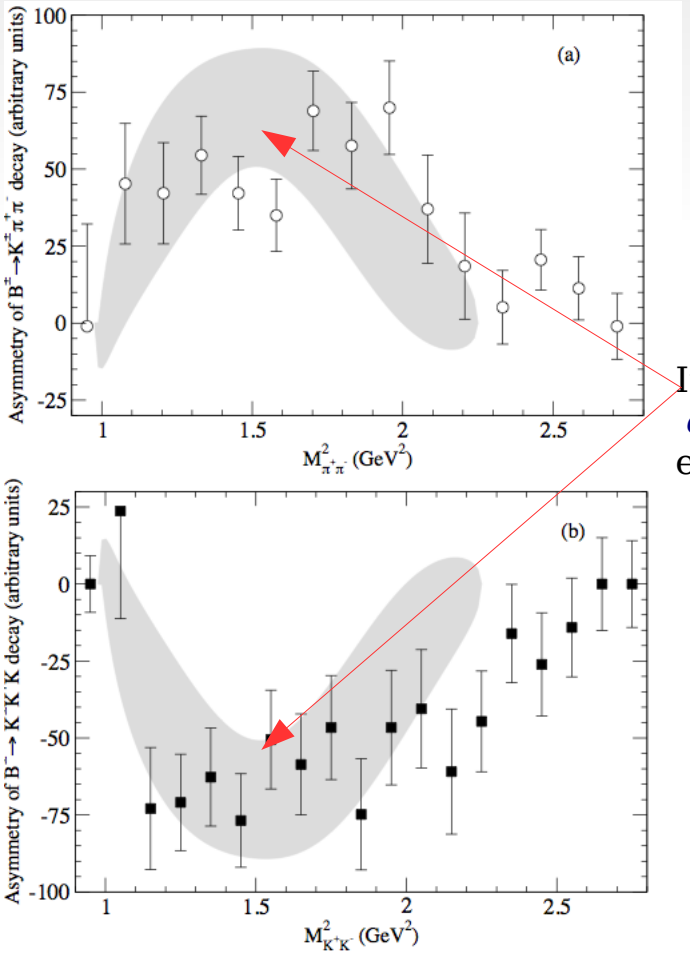
Only 2011 data

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



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





Inelasticity η:compilation *of* $\pi^+\pi^- \to K^+K^-$ experimental results.

J. R. Pelaez, and F. J. Ynduráin, Phys. Rev. D **71**, 074016 (2005).

$\delta_{KK} = \delta_{\pi\pi}$

CP violation induced by interference between S and P wave in

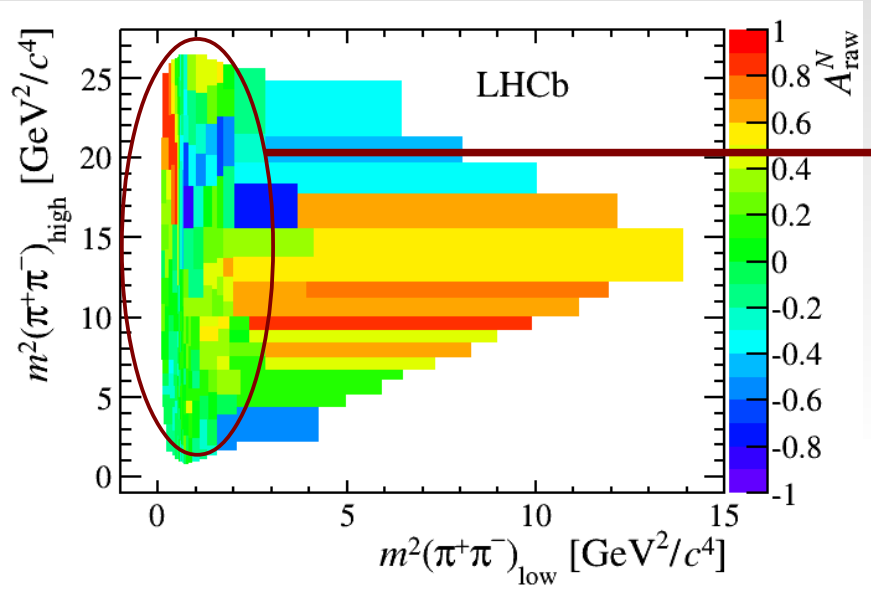
$B^+ \to K^+\pi^+\pi^-$, $B^+ \to \pi^+\pi^+\pi^-$

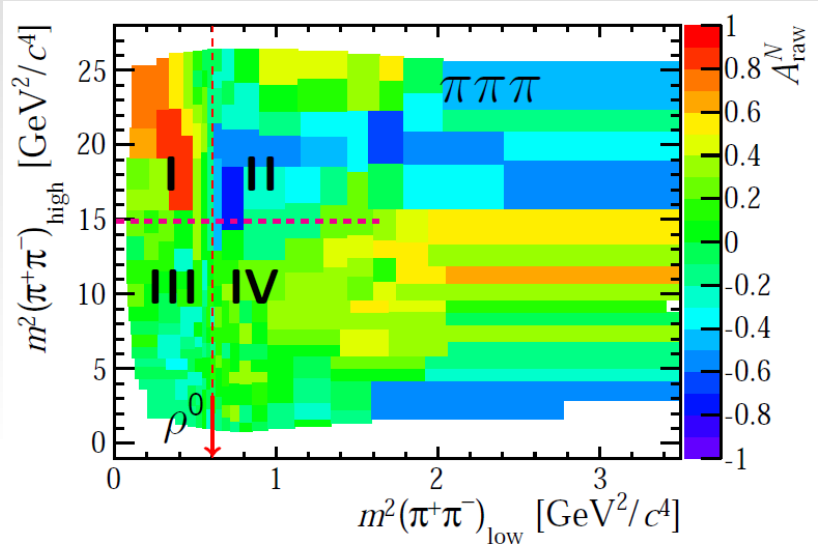
Final results

with LHCb 2011+2012 data

$B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$ Dalitz plot

2011 +2012 data



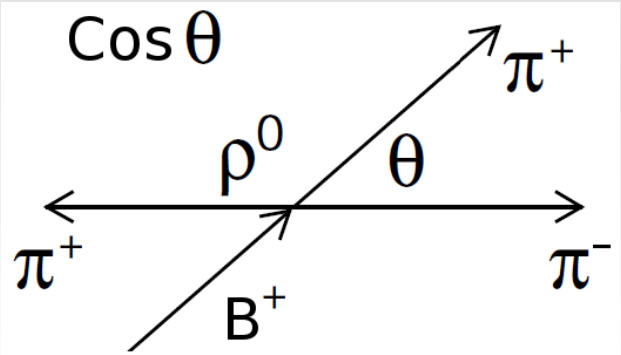


CP violation in $B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$ decay.

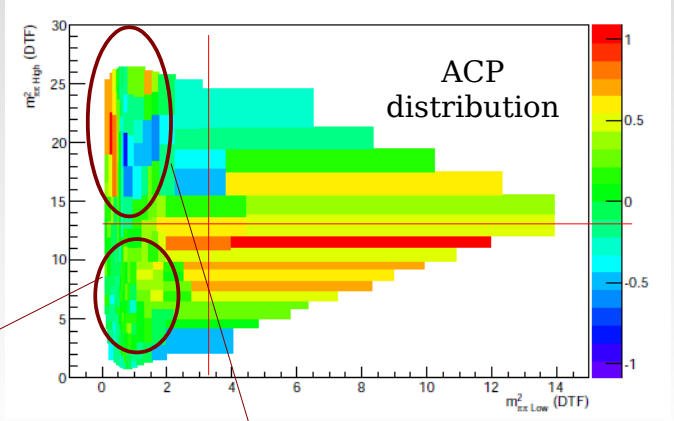
2011 + 2012 data: about 25K $B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$ events

Division related with angular distribution of vector resonances.

Vector resonances

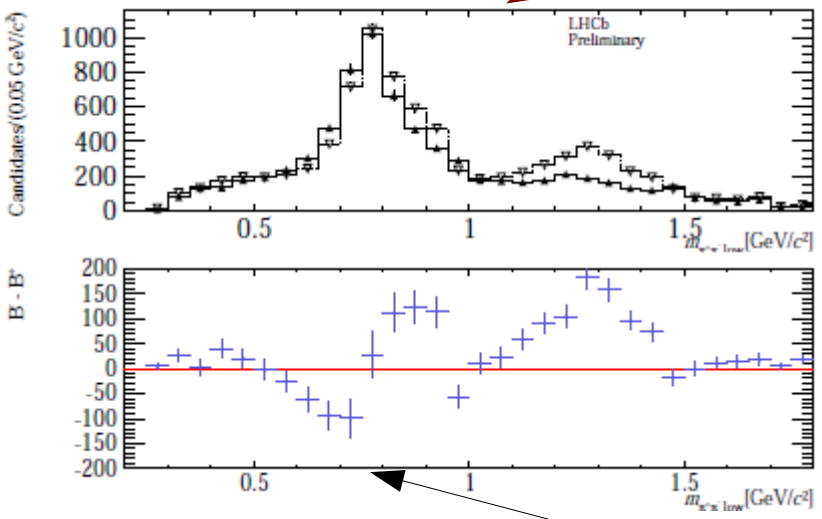


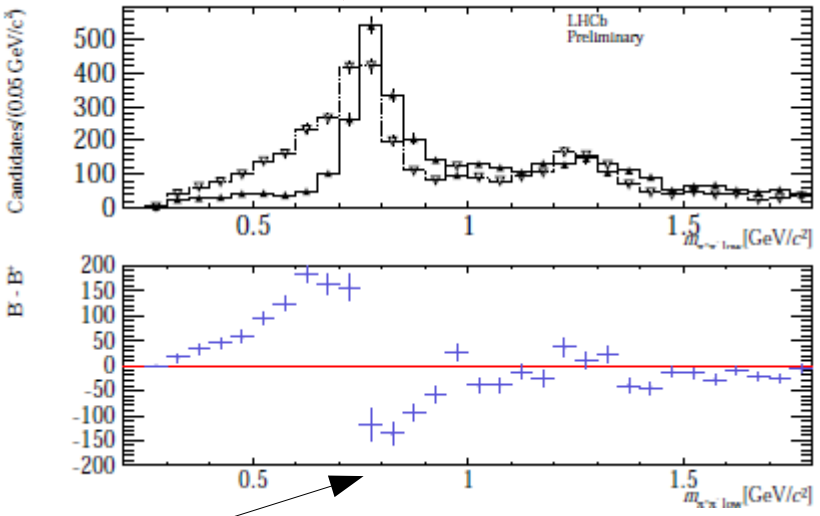
-1< COS Θ < 1



COS Θ < 0

COS Θ > 0

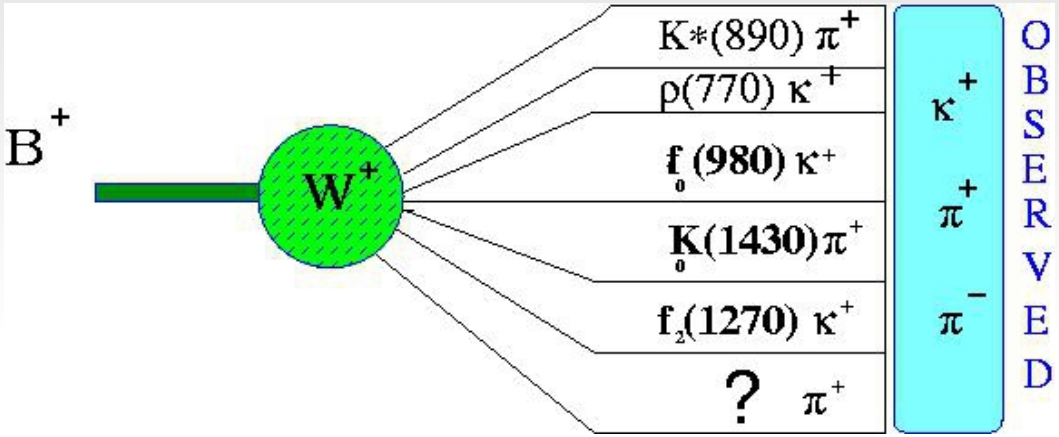


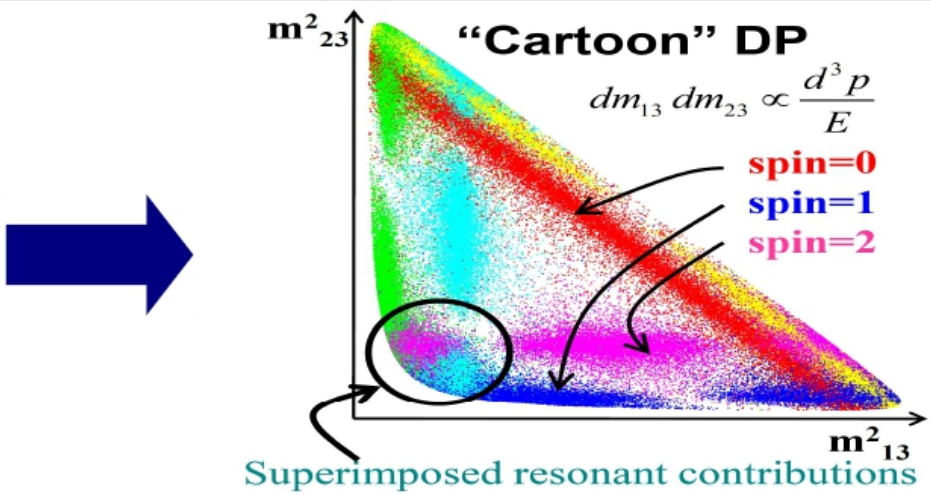


$\rho^0(770)$ invariant mass

Charmless three body B charge decays

- *Study the B decays and their intermediary states:*



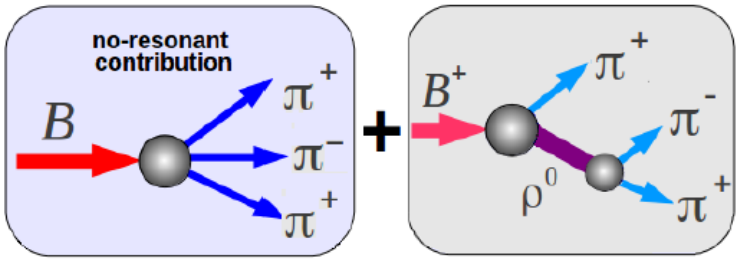


- $B^{\pm} \rightarrow \pi^{\pm} \pi^{+} \pi^{--}$
- $B^{\pm} \rightarrow \pi^{\pm} K^{+} K^{-}$
- $B^{\pm} \rightarrow K^{\pm} K^{+} K^{-}$
- $B^{\pm} \rightarrow \pi^{\pm} p^{-} p$
- $B^{\pm} \rightarrow K^{\pm} p^{-} p$

Interference between intermediary states with different weak and strong phases imply in CP violation.

Heavy meson three body decays.
Amplitude analysis

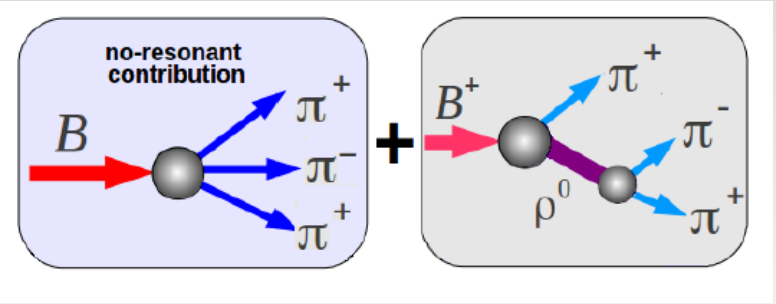
- *Isobaric Model amplitude two body plus one bachelor*
- $A_R = BW_R \times \Theta_R^J$
- BW - Breit Wigner = $\dfrac{1}{m_R^2 - s - i m_R \Gamma_R(s)}$
- Θ_R^J - *angular function*
- *Coherent sum* $A_T = \sum a_i e^{i\delta i} A_R$
- δ_i *is the re-scattering phase*



Work pretty well for charm three body decays.

- *Approximation 2 + 1 work at least in first order.*

Dalitz interference CP asymmetry between ρ(770) and a non resonant scalar amplitude.



Simplest amplitude of $B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$ to low $\pi^{+}\pi^{-}$ invariant mass:
one vector resonance and a scalar non resonant amplitudes.

B positive $\quad \mathcal{M}_{+} = a^{\rho}_{+} e^{i\delta^{\rho}_{+}} F^{\mathrm{BW}}_{\rho} \cos\theta + a^{nr}_{+} e^{i\delta^{nr}_{+}} F^{\mathrm{NR}}$

B negative $\quad \mathcal{M}_{-} = a^{\rho}_{-} e^{i\delta^{\rho}_{-}} F^{\mathrm{BW}}_{\rho} \cos\theta + a^{nr}_{-} e^{i\delta^{nr}_{-}} F^{\mathrm{NR}}$

$\delta^{i}_{+} = \delta^{i}_{s} + \Phi^{i}_{w}$

$\delta^{i}_{-} = \delta^{i}_{s} - \Phi^{i}_{w}$

Breit-Wigner $\quad F^{\mathrm{BW}}_{R}(s) = \dfrac{1}{m^{2}_{R} - s - i m_{R}\Gamma_{R}(s)}$

$F^{NR} = 1$

θ is the Gottfried-Jackson angle to spin 1 resonances:
COS θ change from **-1 to +1**

CP asymmetry from S and P wave interference in same hadronic final state.

I.B., G. Guerrer, J. Miranda -Phys.Rev. D76 (2007) 073011
I.B., I.I. Bigi, A. Gomes, G. Guerrer, J. Miranda and A.C. Dos Reis-Phys. Rev. D80, 096006 (2009)
I.B., I.I. Bigi, A. Gomes, J. Miranda, J. Otalora, A.C. Dos Reis and A. Veiga- Phys. Rev. D86, 036005 (2012)

$$\Delta|\mathcal{M}|^2 = |\mathcal{M}_+|^2 - |\mathcal{M}_-|^2 = [(a_+^\rho)^2 - (a_-^\rho)^2]|F_\rho^{\rm BW}|^2\cos^2\theta + [(a_+^{nr})^2 - (a_-^{nr})^2]|F^{\rm NR}|^2$$
$$+2\cos\theta|F_\rho^{\rm BW}|^2|F^{\rm NR}|^2 \times$$
$$\{(m_\rho^2 - s)[a_+^\rho a_+^{nr}\cos(\delta_+^\rho - \delta_+^{nr}) - a_-^\rho a_-^{nr}\cos(\delta_-^\rho - \delta_-^{nr})]$$
$$-m_\rho\Gamma_\rho[a_+^\rho a_+^{nr}\sin(\delta_+^\rho - \delta_+^{nr}) - a_-^\rho a_-^{nr}\sin(\delta_-^\rho - \delta_-^{nr})]\}$$

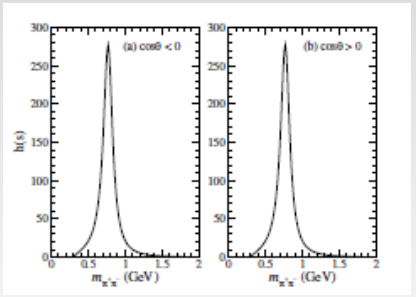
R

I

Short and Long distance signatures in Dalitz plot.

Short distance :

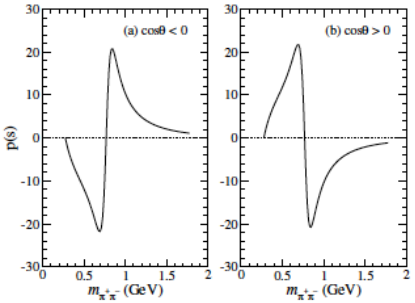
$$\Delta|\mathcal{M}|^2 \propto [(a_+^\rho)^2 - (a_-^\rho)^2]|F_\rho^{\rm BW}|^2 \cos^2\theta$$



Long distance interference S and wave interaction:

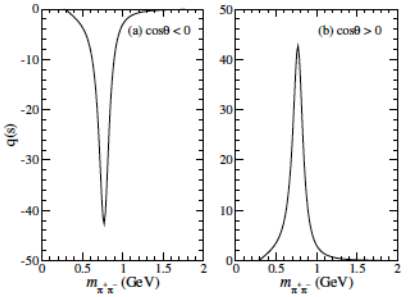
Real part of Dalitz CP asymmetry

$$\Delta^R|\mathcal{M}|_I^2 \propto \frac{\cos\theta(m_\rho^2 - s)}{(m_\rho^2 - s)^2 + m_R^2\Gamma_R^2}$$



Imaginary part of Dalitz CP asymmetry

$$\Delta^I|\mathcal{M}|_I^2 \propto \frac{\cos\theta m_\rho^2\Gamma_\rho^2}{(m_\rho^2 - s)^2 + m_R^2\Gamma_R^2}$$

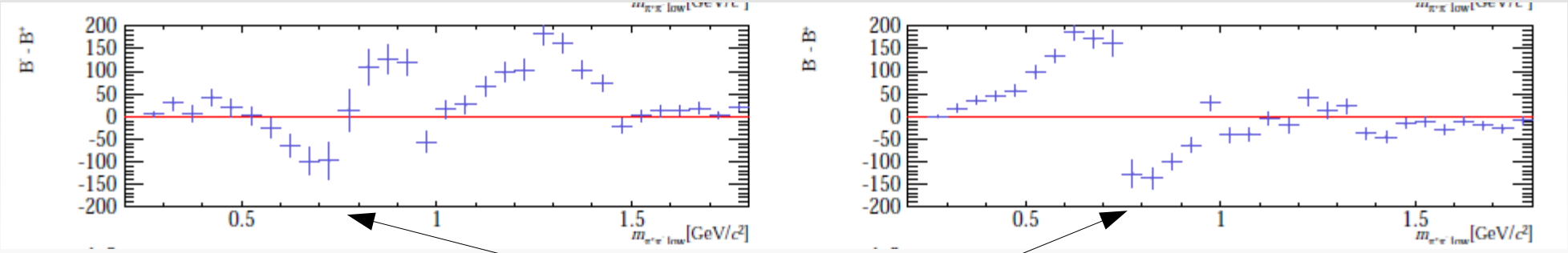


In the two last cases CPT is naturally conserved

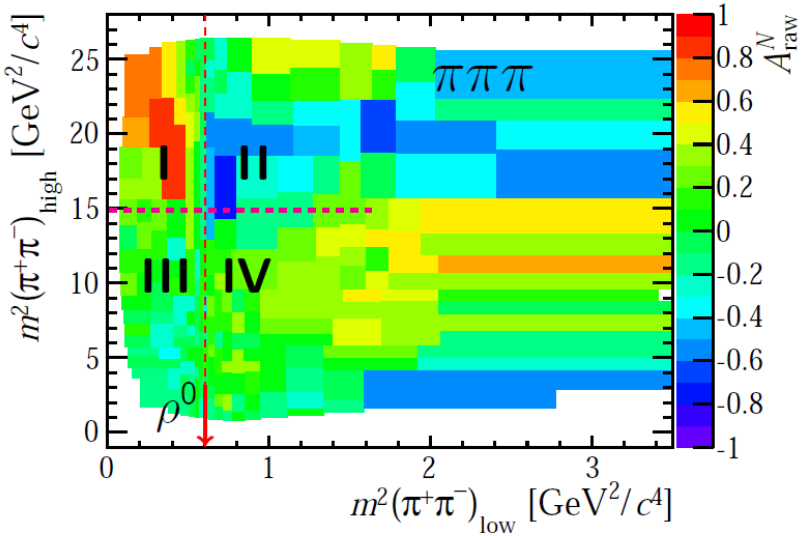
CP violation in $B^{\mp} \rightarrow \pi^{\mp}\pi^{+}\pi^{-}$ decay.

COS Θ < 0

COS Θ > 0



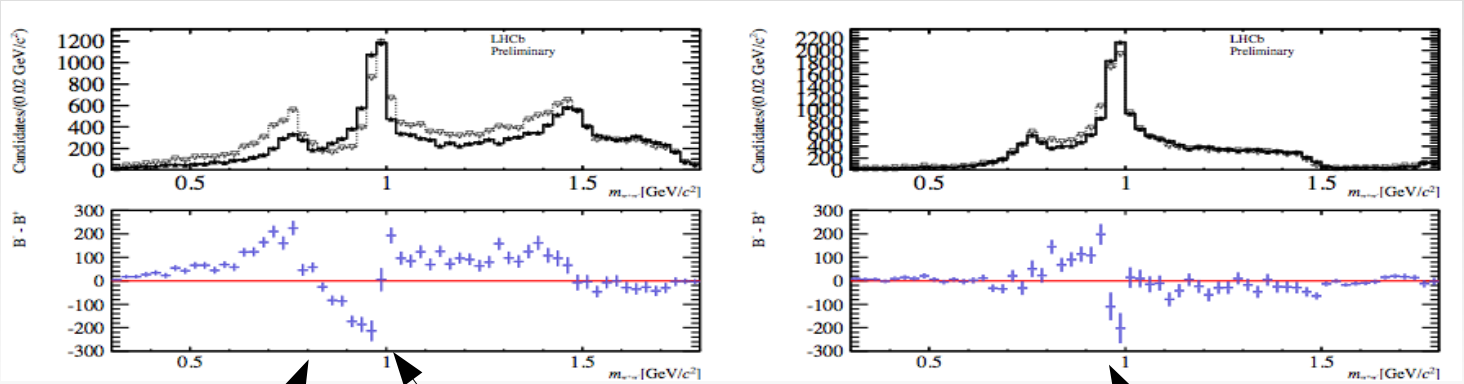
The zero at the ρ(770) mass, in both sides of the COS Θ distribution is an indication of dominant contribution of the of the real part of the Dalitz CP violation.



CP violation in $B^{\mp} \rightarrow K^{\mp}\pi^{+}\pi^{-}$ decay.

COS Θ < 0

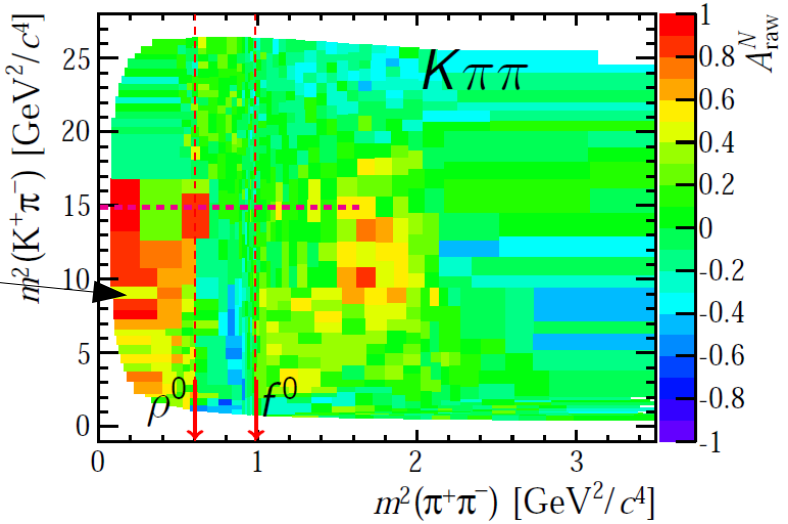
COS Θ > 0



The zero around the ρ(770) and f0(980) masses, only in cos Θ>0 distributions, indicating a dominance for the real part of Dalitz interference CP asymmetry

The zero around the f0(980) masses to cos Θ<0, but nothing clear around ρ(770).

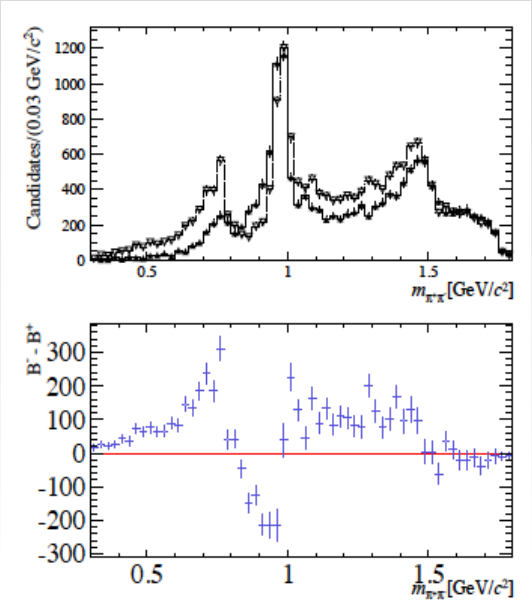
CP asymmetry close with 60%



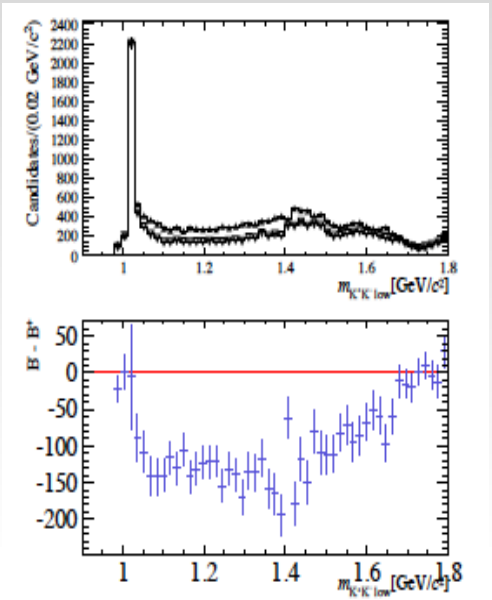
Putting together re-scattering and S and P interference

LHCb results: projections

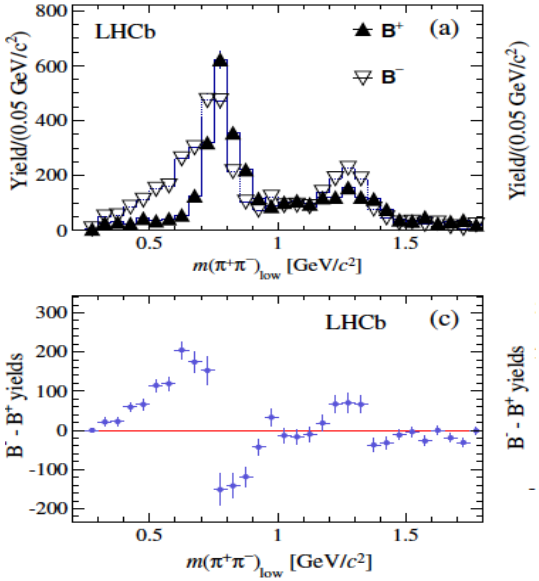
$B^+ \to K^+\pi^+\pi^-$



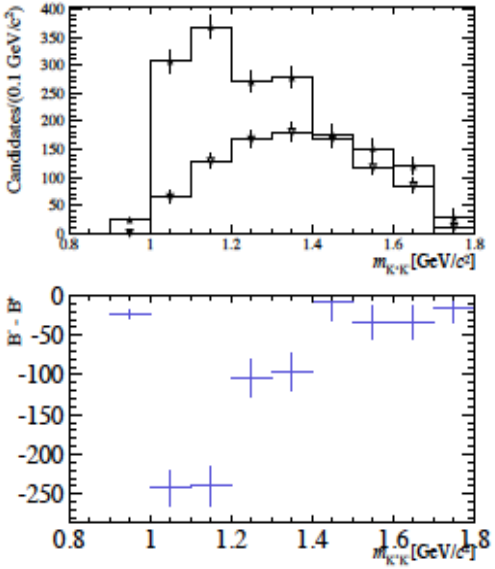
$B^+ \to K^+K^+K^-$



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

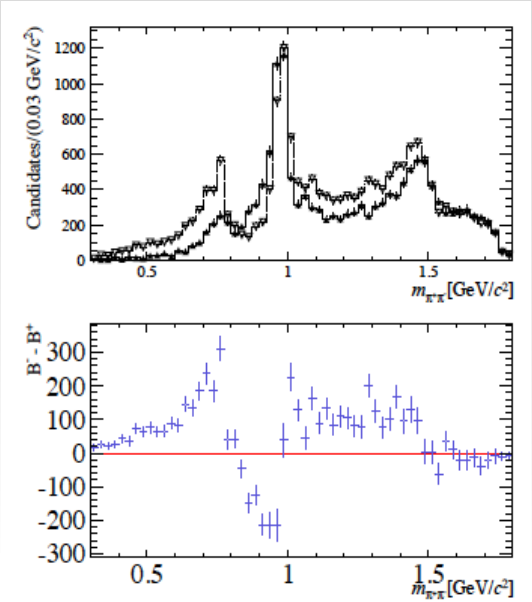


$B^+ \to K^+K^+\pi^-$

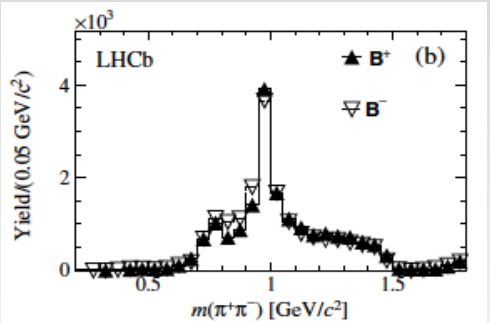


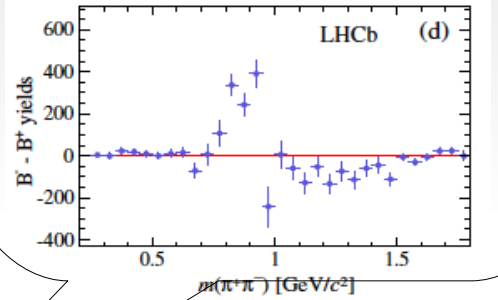
LHCb results: projections

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



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



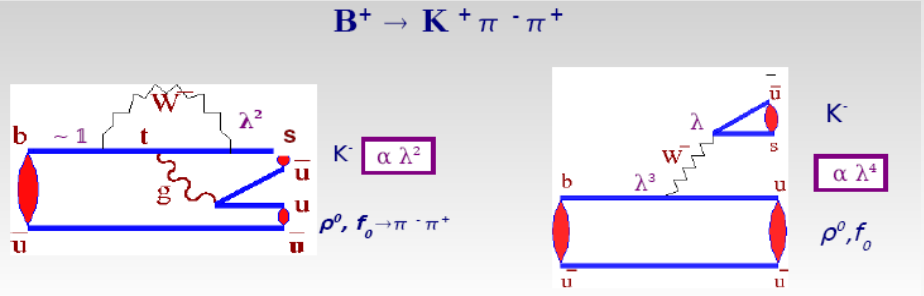


We did not consider this plot since we assume an interference with another source of CP assymetry

Dalitz interference CP asymmetry between ρ(770), f_0(980), non resonant, $K^+ K^+ \to \pi^+\pi^-$.

CP violation: Dalitz interference, CPT, and final state interactions - J.H. Alvarenga Nogueira, I. B., A.B.R. Cavalcante, T. Frederico, O. Lourenço. Phys.Rev. D92 (2015) 5, 054010.

$$\langle \lambda_0 | H_w | h \rangle = A_{0\lambda} + e^{-\imath\gamma} B_{0\lambda},$$
$$\langle \overline{\lambda}_0 | H_w | \overline{h} \rangle = A_{0\lambda} + e^{+\imath\gamma} B_{0\lambda},$$



For our propose we need only these amplitudes in the Isobar mode

$$\mathcal{A}^{\pm}_{0\lambda} = a^{\rho}_0 F^{\rm BW}_{\rho} k(s)\cos\theta + a^{f}_0 F^{\rm BW}_{f} + \frac{a^{nr}_{0\lambda} + b^{nr}_{0\lambda} e^{\pm i\gamma}}{1+\frac{s}{\Lambda^2_\lambda}} + [b^{\rho}_0 F^{\rm BW}_{\rho} k(s)\cos\theta + b^{f}_0 F^{\rm BW}_{f}] e^{\pm i\gamma},$$

+

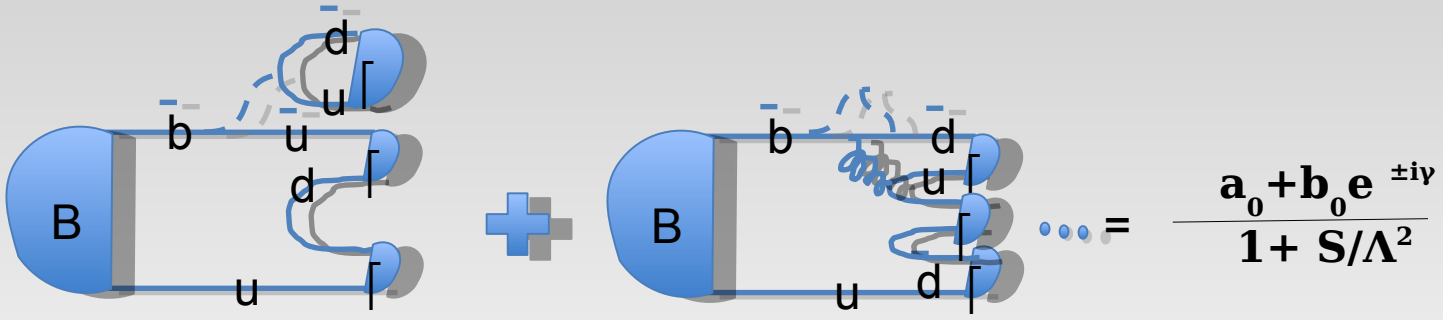
the S matrix

$$S = \begin{bmatrix} \eta e^{2i\delta_{\pi\pi}} & i\sqrt{1-\eta^2}\, e^{i(\delta_{\pi\pi}+\delta_{KK})} \\ i\sqrt{1-\eta^2}\, e^{i(\delta_{\pi\pi}+\delta_{KK})} & \eta e^{2i\delta_{KK}} \end{bmatrix}$$

$$F^{\rm BW}_R(s) = \frac{1}{m^2_R - s - i m_R \Gamma_R(s)}$$

Note that in our formalism, the Penguin does not need to have a strong phase

Non-resonant amplitude and $K^+K^+ \to \pi^+\pi^-$ parameters



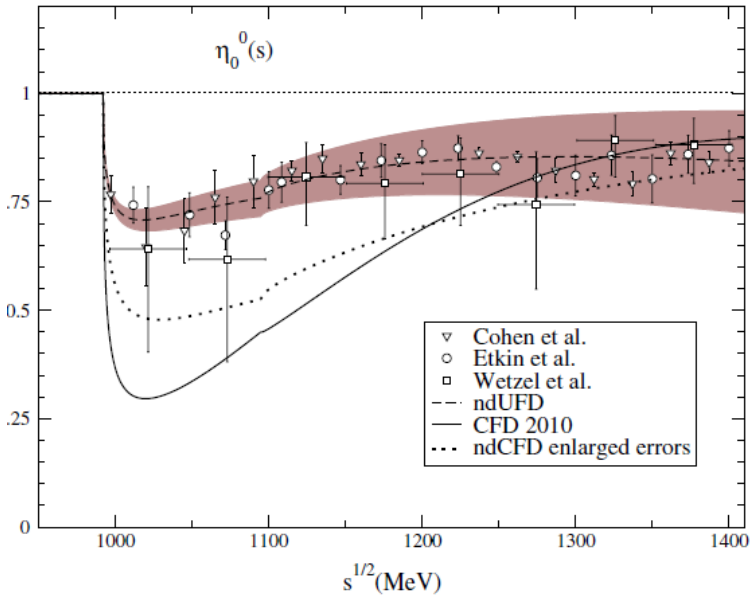
This form factor carries a momentum scale associated with the overlap function between the B and pion states, which should reflect a spatial region with size smaller then the B meson.

Parametrization to the inelasticity factor give big uncertainty

$$\eta_0^{(0)} = 1 - \left(\epsilon_1 \frac{k_2}{s^{1/2}} + \epsilon_2 \frac{k_2^2}{s}\right) \frac{M'^2 - s}{s};$$

$$\epsilon_1 = 2.4 \pm 0.2, \quad \epsilon_2 = -5.5 \pm 0.8;$$

k_2 is a kinematic factor $k_2 = \frac{\sqrt{s - 4m_K^2}}{2},$



J. R. Pelaez, and F. J. Ynduráin, Phys. Rev. D **71**, 074016 (2005).

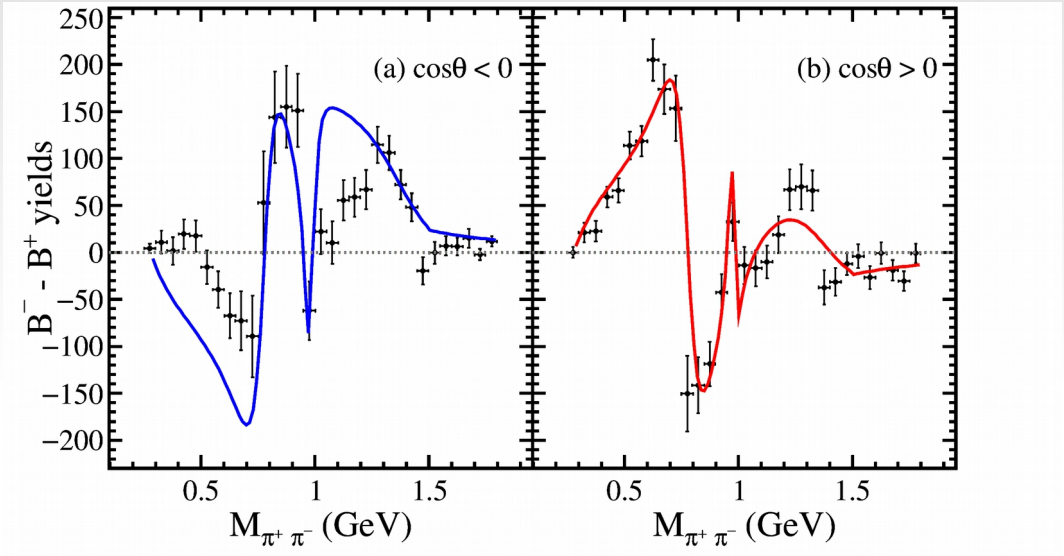
Amplitude Square

Taking the amplitude square and keeping only terms that are compatible with CPT, we found to the difference of the partial width the expression for the $B^+ \to K^+\pi^+\pi^-$:

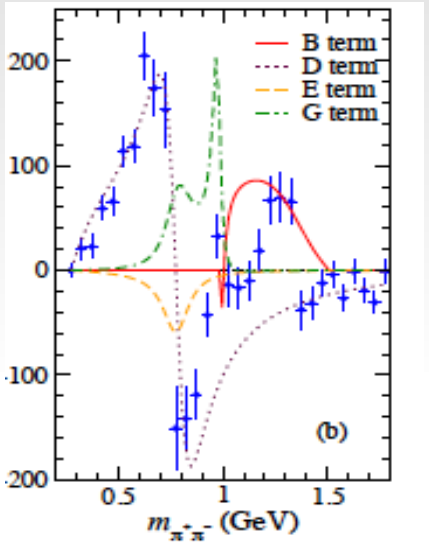
$$
\begin{aligned}
\Delta\Gamma_\lambda &= \frac{\mathcal{B}\cos[2\delta_{\pi\pi}(s)]\sqrt{1-\eta^2(s)}}{\left(1+\frac{s}{\Lambda_\lambda^2}\right)\left(1+\frac{s}{\Lambda_{\lambda'}^2}\right)} + |F_\rho^{\rm BW}(s)|^2 k(s)\cos\theta \times \\
&\times \left\{\frac{\mathcal{D}(m_\rho^2-s)}{1+\frac{s}{\Lambda_\lambda^2}} + \frac{\mathcal{E}m_\rho\Gamma_\rho(s)}{1+\frac{s}{\Lambda_\lambda^2}}\right\} + F_\rho^{\rm BW}(s)|^2|F_f^{\rm BW}(s)|^2 k(s)\cos\theta \times \\
&\times \left\{\mathcal{F}[(m_\rho^2-s)(m_f^2-s)+m_\rho\Gamma_\rho(s)m_f\Gamma_f(s)]\right. \\
&+ \left.\mathcal{G}[(m_\rho^2-s)m_f\Gamma_f(s)-m_\rho\Gamma_\rho(s)(m_f^2-s)]\right\},
\end{aligned}
$$

CP violation in $B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$ and $B^{\mp} \to \pi^{\mp}K^{+}K^{-}$ Decays

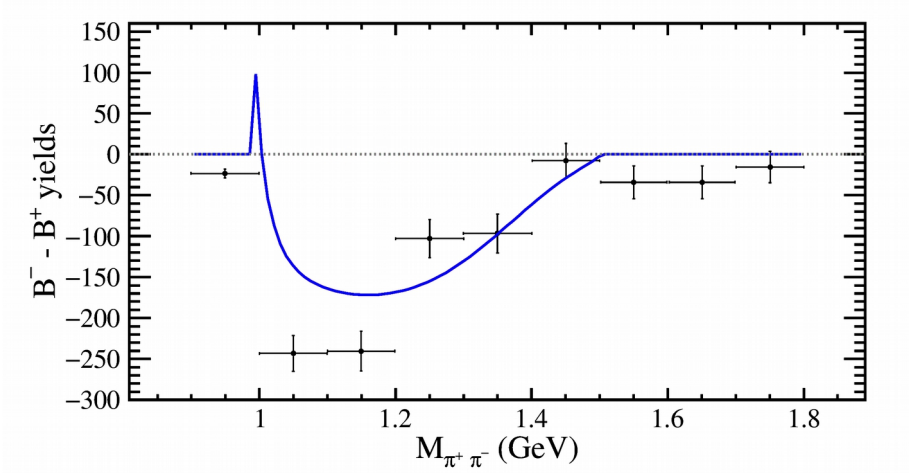
$B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$



S and P wave interference and Re-scattering $K^+K^- \to \pi^+\pi^-$



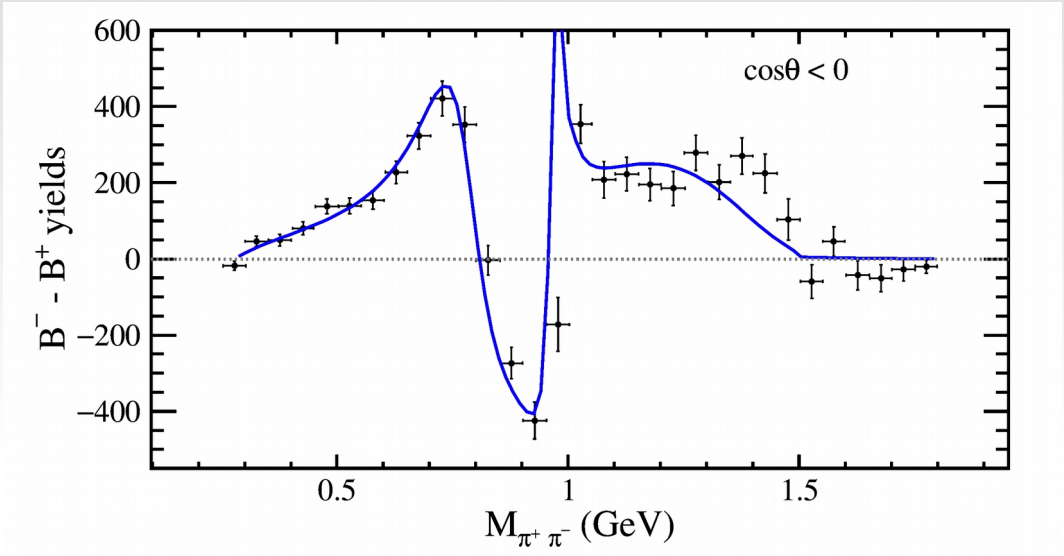
$B^{\mp} \to \pi^{\mp}K^{+}K^{-}$



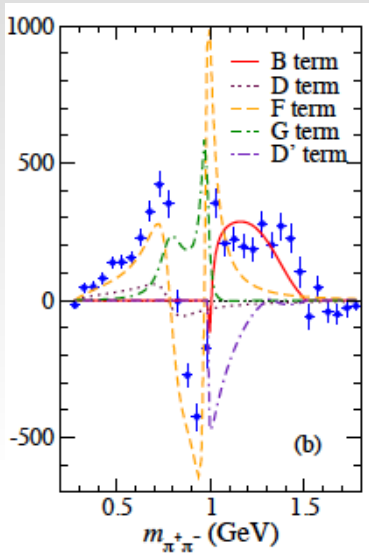
Re-scattering $\pi^+\pi^- \to K^+K^-$

CP violation in $B^{\mp} \to K^{\mp}\pi^{+}\pi^{-}$ and $B^{\mp} \to K^{\mp}K^{+}K^{-}$ Decays

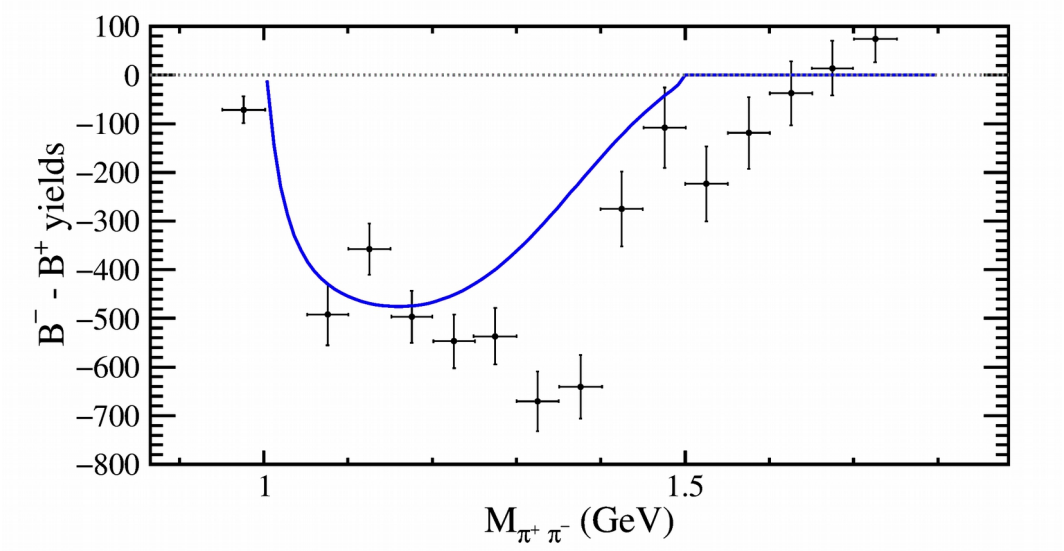
$B^{\mp} \to K^{\mp}\pi^{+}\pi^{-}$



S and P wave interference and Re-scattering $K^+K^- \to \pi^+\pi^-$



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



Re-scattering $\pi^+\pi^- \to K^+K^-$

Summary

- *CPT constraint must be take in account in three body charmless B decay.*
- *We propose a general formalism using CPT constraint.*
- *CP violation in* $B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$ *and* $B^{\mp} \to \pi^{\mp}K^{+}K^{-}$ *decays seems present together compatibility with CPT constraint.*
- *CP violation in* $B^{\mp} \to K^{\mp}\pi^{+}\pi^{-}$ *and* $B^{\mp} \to K^{\mp}K^{+}K^{-}$ *decays seems present together compatibility with CPT constraint.*
- *S and P wave interference has a clear signature in CP violation distributions*
- *Amplitude* $\pi^{+}\pi^{-} \to K^{+}K^{-}$ *play an important rule in these decays.*
- *Amplitude analysis must improve this preliminary analysis.*

Backcup

CP violation induced by Dalitz interference

$B^{+-} \to K^{+} p \bar{p}$

Final results

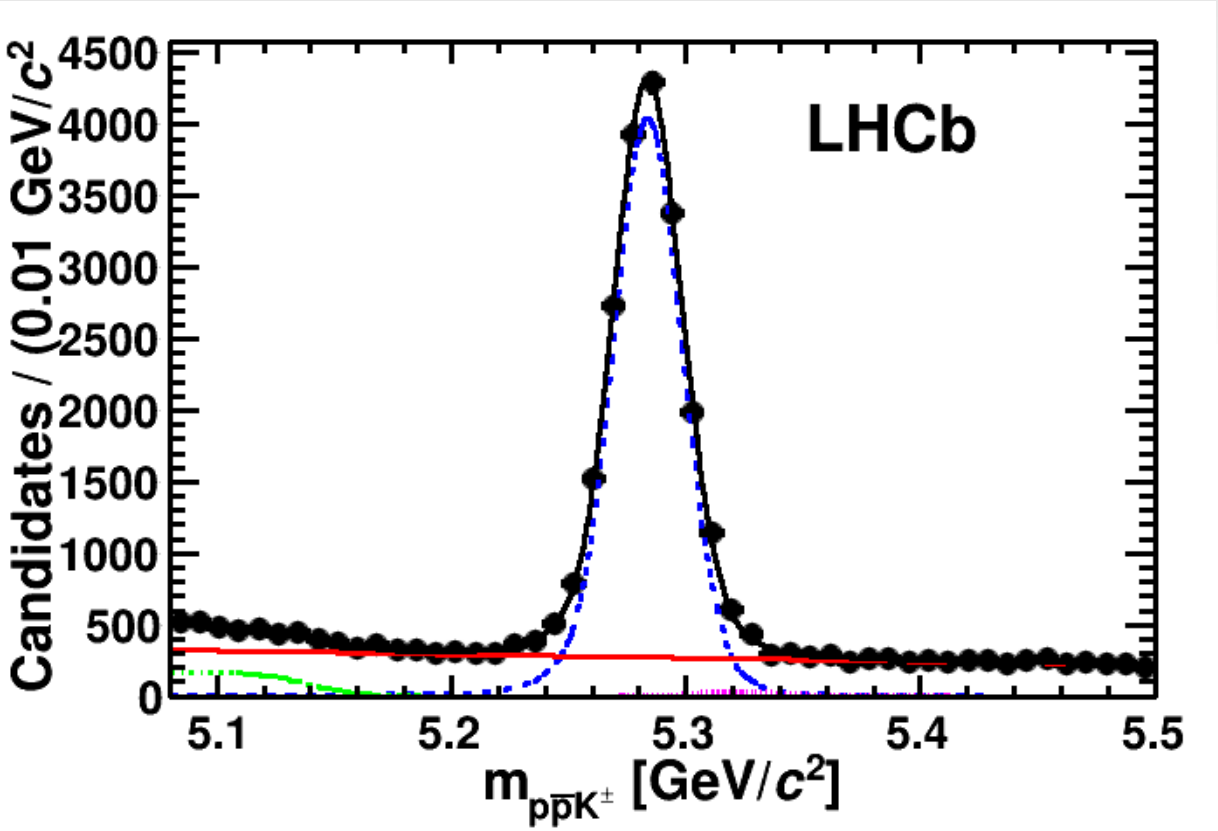
with LHCb 2011 +2012 data

hep/ex-1407.5907 to appear at PRL

Total charge asymmetry for $B^{\mp} \rightarrow K^{\mp} p\ p$

R. Aaij *et al.* (LHCb Collaboration)Phys. Rev. Lett. 113, 141801

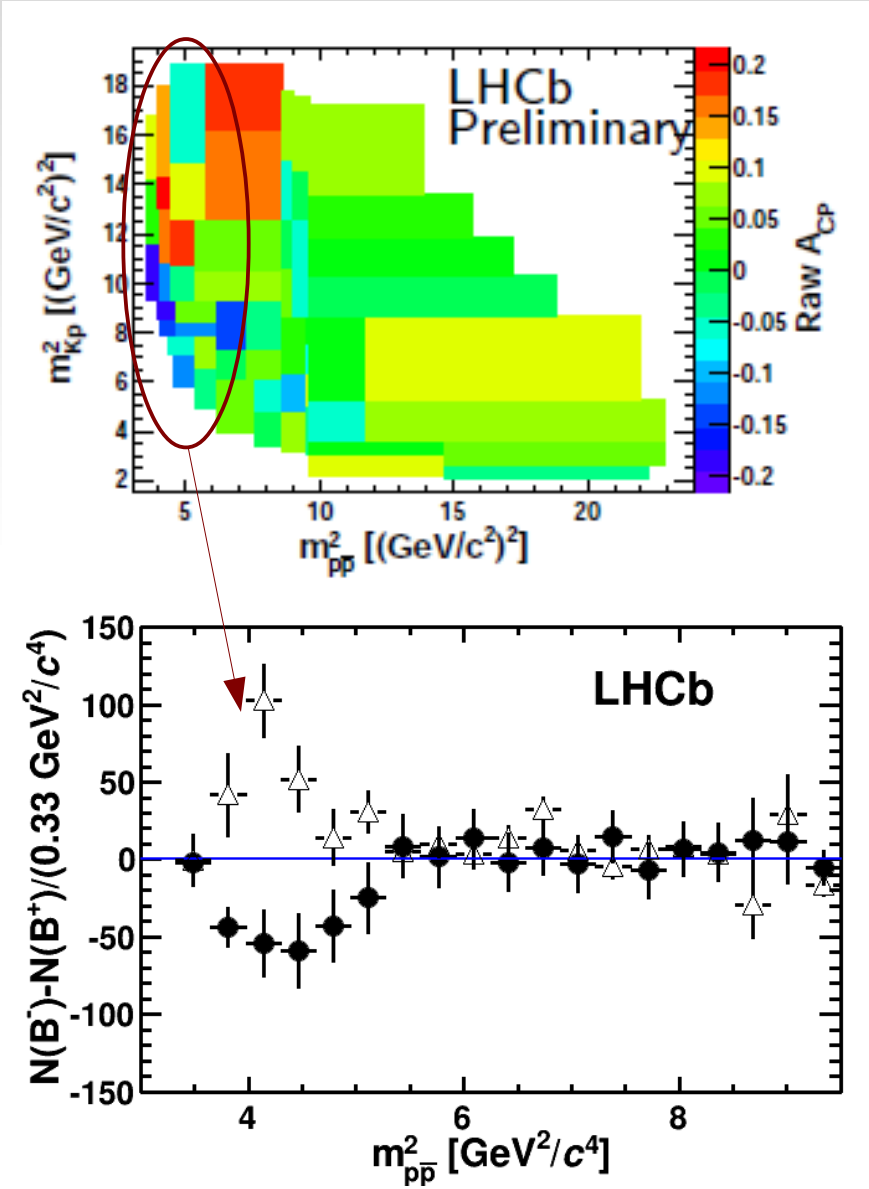
$$N(B^-) + N(B^+) = 18.721 \pm 142$$



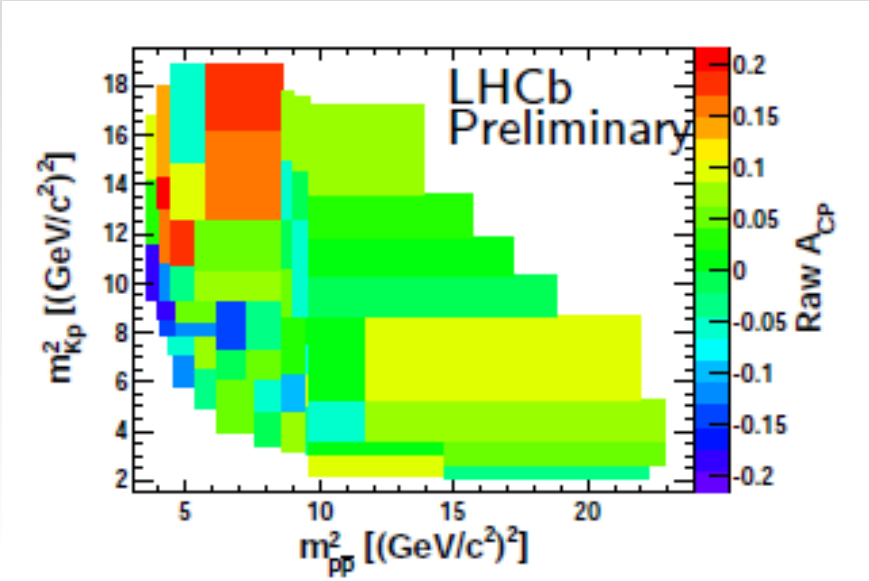
Total charge asymmetry:

$$ACP = \frac{N(B^-) - N(B^+)}{N(B^-) + N(B^+)} = 2.2 \pm 2.0(\text{sta}) \pm 0.4(\text{sys})\%$$

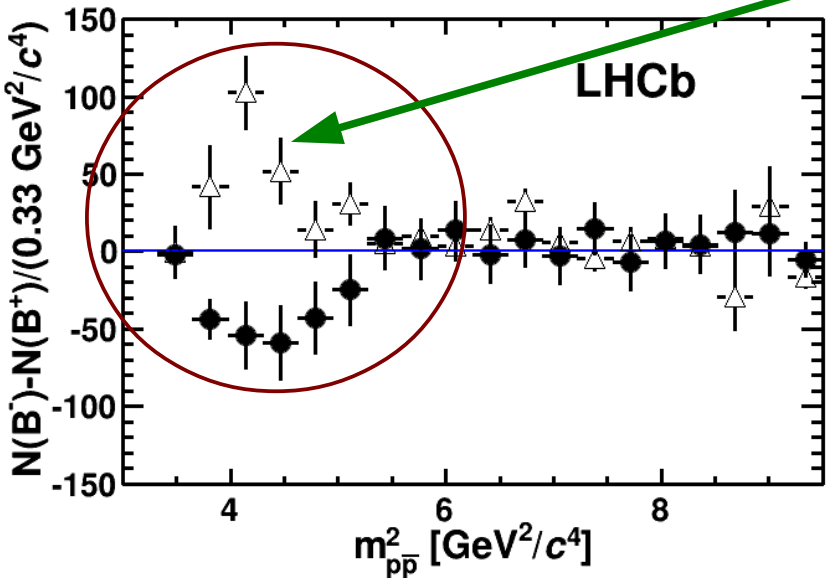
$B^{\mp} \to K^{\mp} p \bar{p}$ Dalitz plot



$B^{\mp} \to K^{\mp} p \bar{p}$ Dalitz plot



ACP = 9.6 ± 2.4(sta) ± 0.4(sys)%



First evidence of CP violation involving baryons.