~~CP~~ violation in three-body B decays: present and near future

St. Augustine's ~~church~~

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

14-18 January 2019 Mainz Institute for Theoretical Physics

Overview

- General questions about CP violation
- CP violation in three body decays
- Experimental evidences of CP violation in $B^{\mp} \rightarrow \pi^{\mp}\pi^{+}\pi^{-}$, $B^{\mp} \rightarrow \pi^{\mp}K^{+}K^{-}$, $B^{\mp} \rightarrow K^{\mp}\pi^{+}\pi^{-}$ and $B^{\mp} \rightarrow K^{\mp}K^{+}K^{-}$ decays.
- Long distance CP violation 1: S and P wave interference
- Long distance CP violation 2: re-scattering $\pi^{+}\pi^{-} \rightarrow K^{+}K^{-}$
- Putting together in a phenomenological approach: coupling channels and CPT invariance
- Importance of CPT constraint in CP violation in three body B decays
- Near future

General questions about ~~CP~~ Violation.

C̸P violation and the CPT Theorem

CP violation → presence of weak phase

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

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

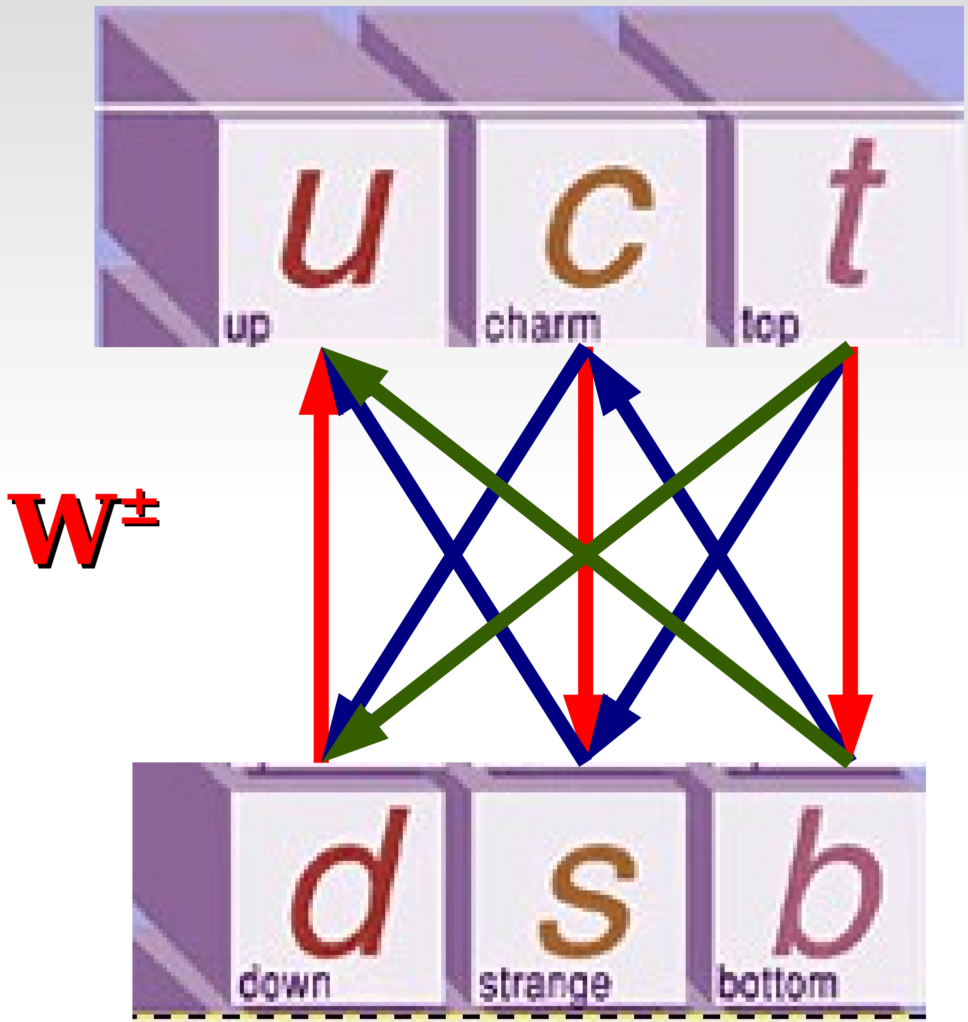
$$\Gamma(M^+ \to f^+_1) + \ldots\ldots + \Gamma(M^+ \to f^+_n) = \Gamma(M^- \to f^-_1) + \ldots\ldots + \Gamma(M^- \to f^-_n)$$

- C̸P violation ⇒ *p.ex.* $\Gamma_1 (M^+ \to f^+_1) > \Gamma_1(M^- \to f^-_1)$.

Exact symmetry ⇒ exact proportion: so it can not be assumed by chance

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

CabbiboKobayashiMaskawa Matrix



High probability

Middle probability

Low probability

$$
\begin{array}{c} \\ \\ \\ \\ \end{array}
\begin{array}{ccc} d & s & b \end{array}
$$

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

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

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).

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

CP Violation:
Datta presentation

$$\Gamma\,(i \to f) - \Gamma\,(\overline{i \to f}) = \left|\langle f|T|i\rangle\right|^2 - \left|\langle \bar{f}|T|\bar{i}\rangle\right|^2 = -4 A_1 A_2 \sin(\delta_1 - \delta_2) \sin(\phi_1 - \phi_2)$$

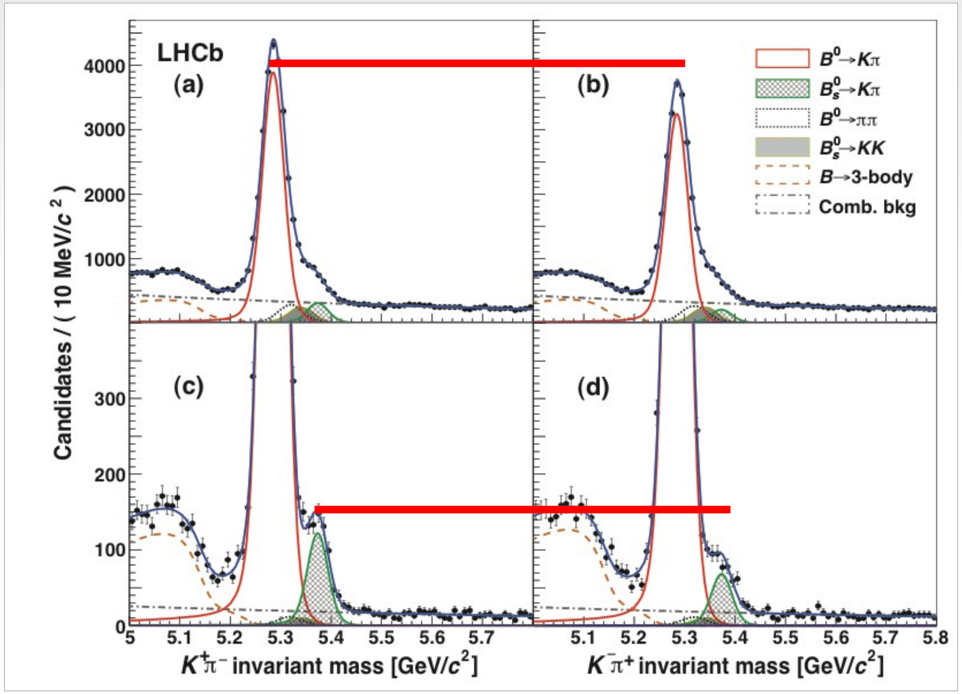
So CP Violation needs: different strong δ_1 and δ_2 and weak phases ϕ_1 and ϕ_2 .

Directly C̸P 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.

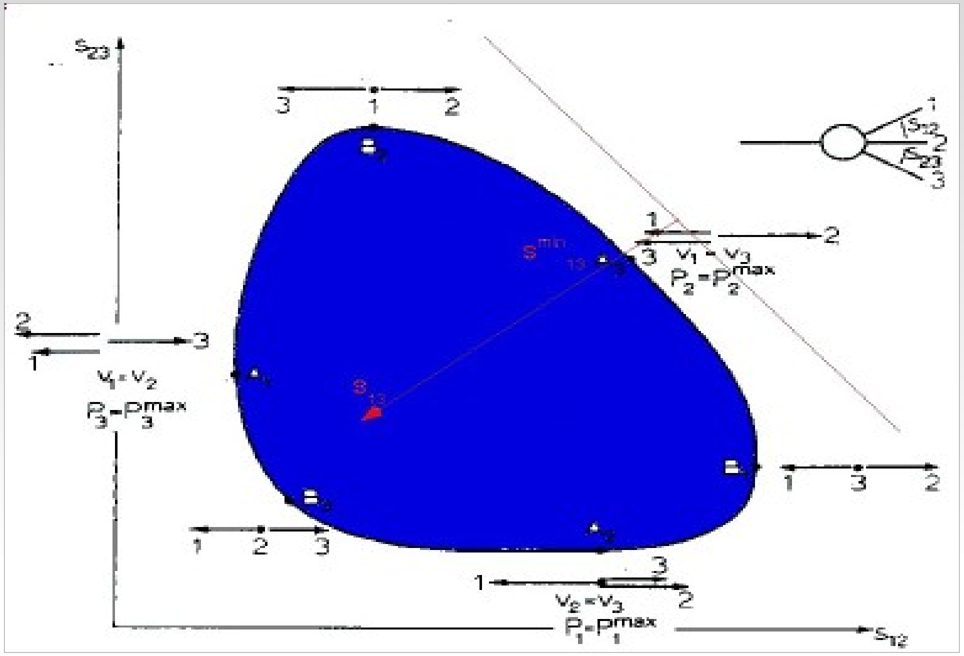


$$A_{cp}(B^0 \rightarrow K^+\pi^-) = \frac{|\langle K^+\pi^- | T | B^0\rangle|^2 - |\langle K^-\pi^+| T | \bar{B}^0\rangle|^2}{|\langle K^+\pi^- | T | B^0\rangle|^2 + |\langle K^-\pi^+| T | \bar{B}^0\rangle|^2}$$

~~CP~~ violation

in charged three meson B decays

Dalitz Plot

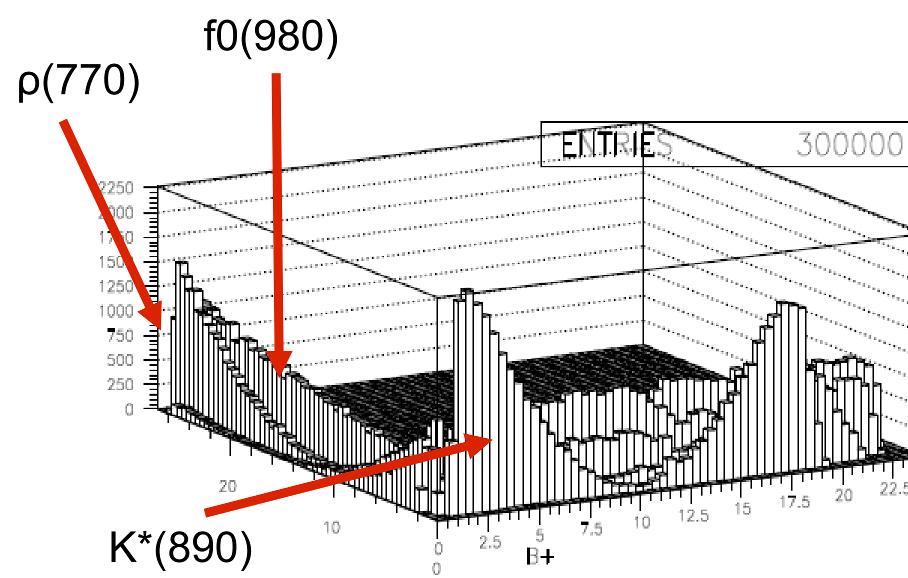


$$s_{12} = M_{12}^2 = (p_1^\nu + p_2^\nu)^2$$
$$s_{13} = M_{13}^2 = (p_1^\nu + p_3^\nu)^2$$
$$s_{23} = M_{23}^2 = (p_2^\nu + p_3^\nu)^2$$

Flat phase space where it is write the dynamics.

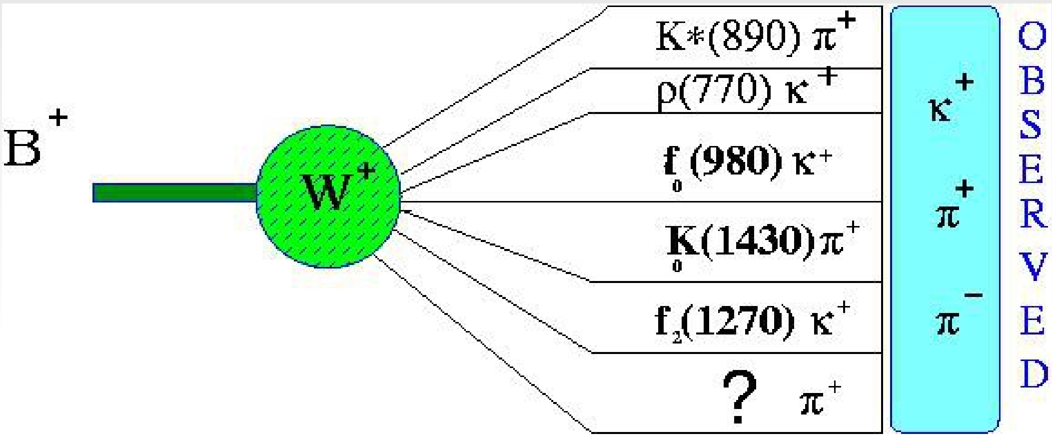
$$d\Gamma(s_{12}, s_{23}) = \frac{1}{(2\pi)^3 32 M_B^3} |\mathcal{M}|^2 \, ds_{12} ds_{23}$$

$| M |^2 \Rightarrow$ resonances + rescattering + NR

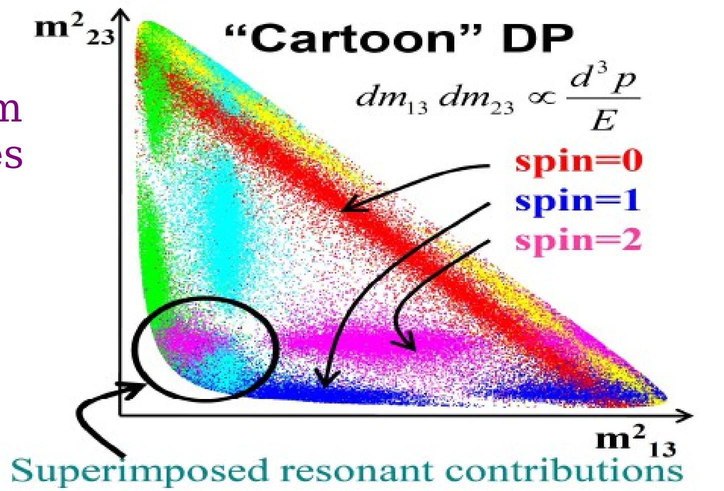


Charmless three body B charge decays

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



Coherent sum of amplitudes



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

Strong hadronic phases difference between intermediary states.

If they have different weak phases ⇒ in CP violation.

CP violation in three body decays:

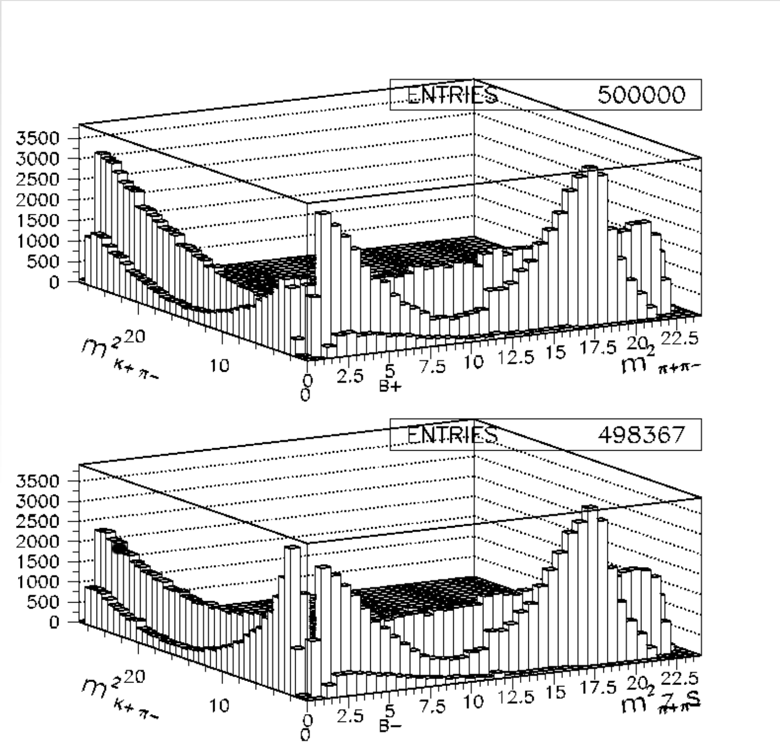
Difference between the two Dalitz plane.

$\Downarrow$

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

$$\neq$$

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



Able to identify:

1- Direct CP violation of a B → R h.

2- CP phases differences between two intermediary amplitudes belong to the same final state.

3- CP phases differences between two intermediary amplitudes belong to different final state.

Phases in Dalitz plot

Clear signature of the phase difference
between two interfering resonances

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

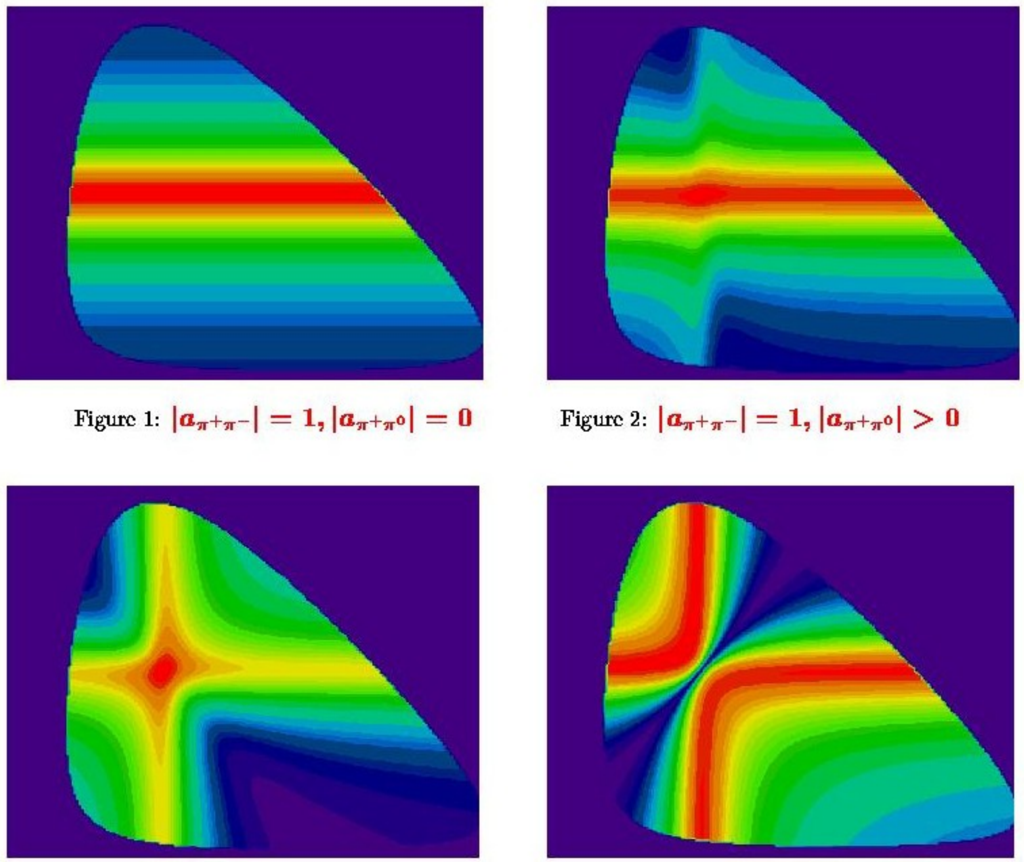


Figure 1: $|a_{\pi^+\pi^-}| = 1, |a_{\pi^+\pi^0}| = 0$

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

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

Final results

with LHCb 2011 +2012 data

Phys.Rev. D90 (2014) 11, 112004

Inclusive result

- CP asymmetries measured in full phase space:

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

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

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

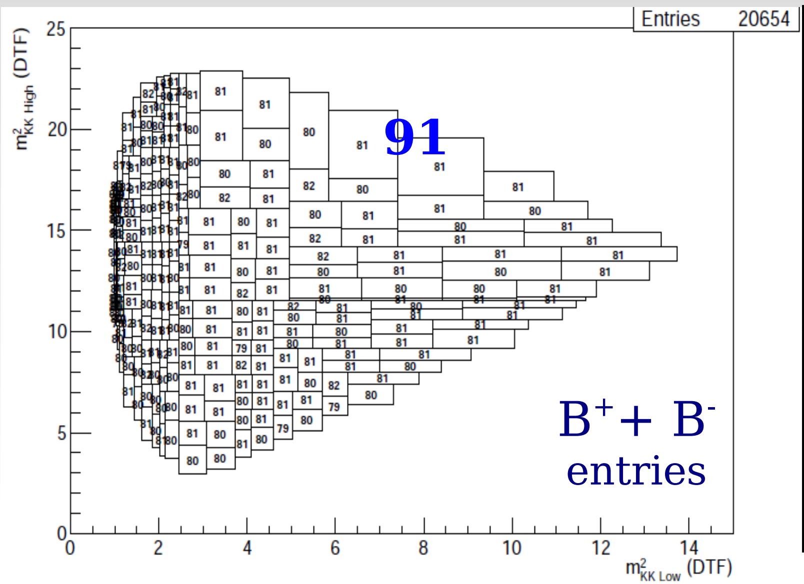
$$A_{CP}(B^{\pm} \to \pi^{\pm}K^{+}K^{-}) = -0.123 \pm 0.017 \pm 0.012 \pm 0.007,$$

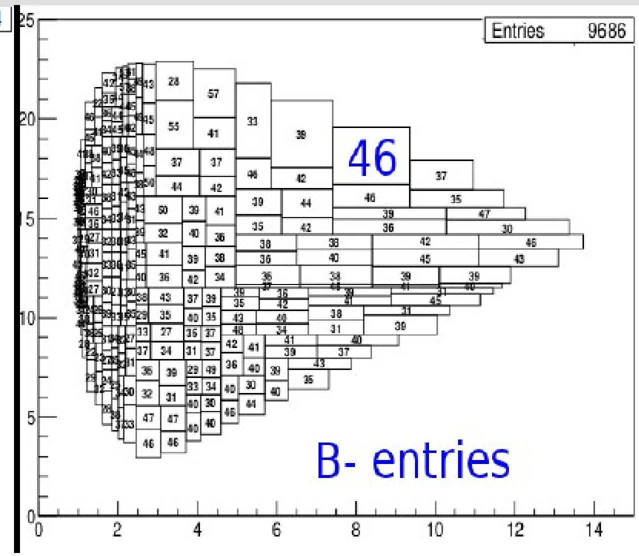
LHCb 2011 +2012 data

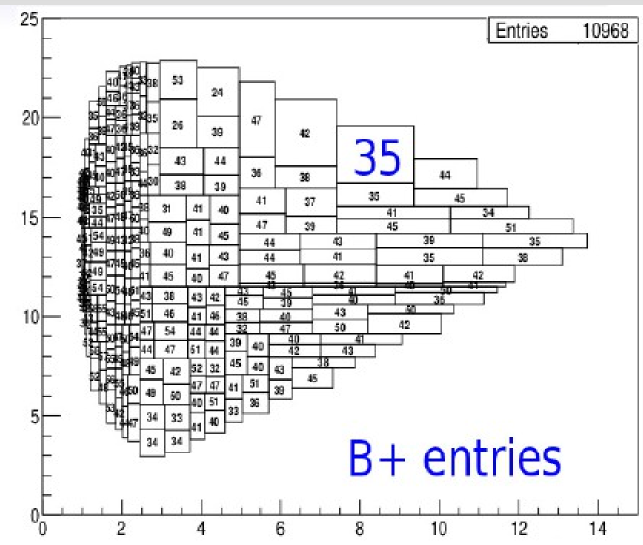
Phys.Rev. D90 (2014) 11, 112004

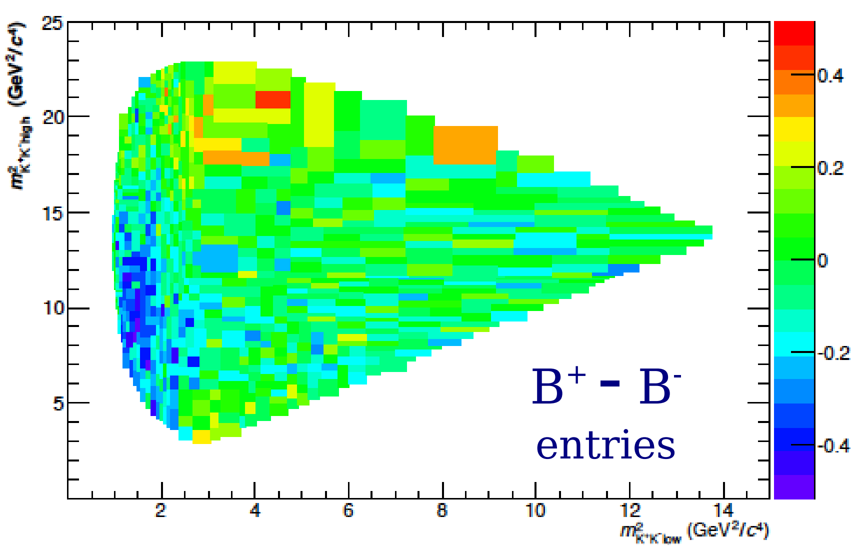
B^+ - B^- Dalitz differences

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









Simetrical Dalitz

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

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

and

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

Otherwise ....

PHYSICAL REVIEW D 90, 112004 (2014)

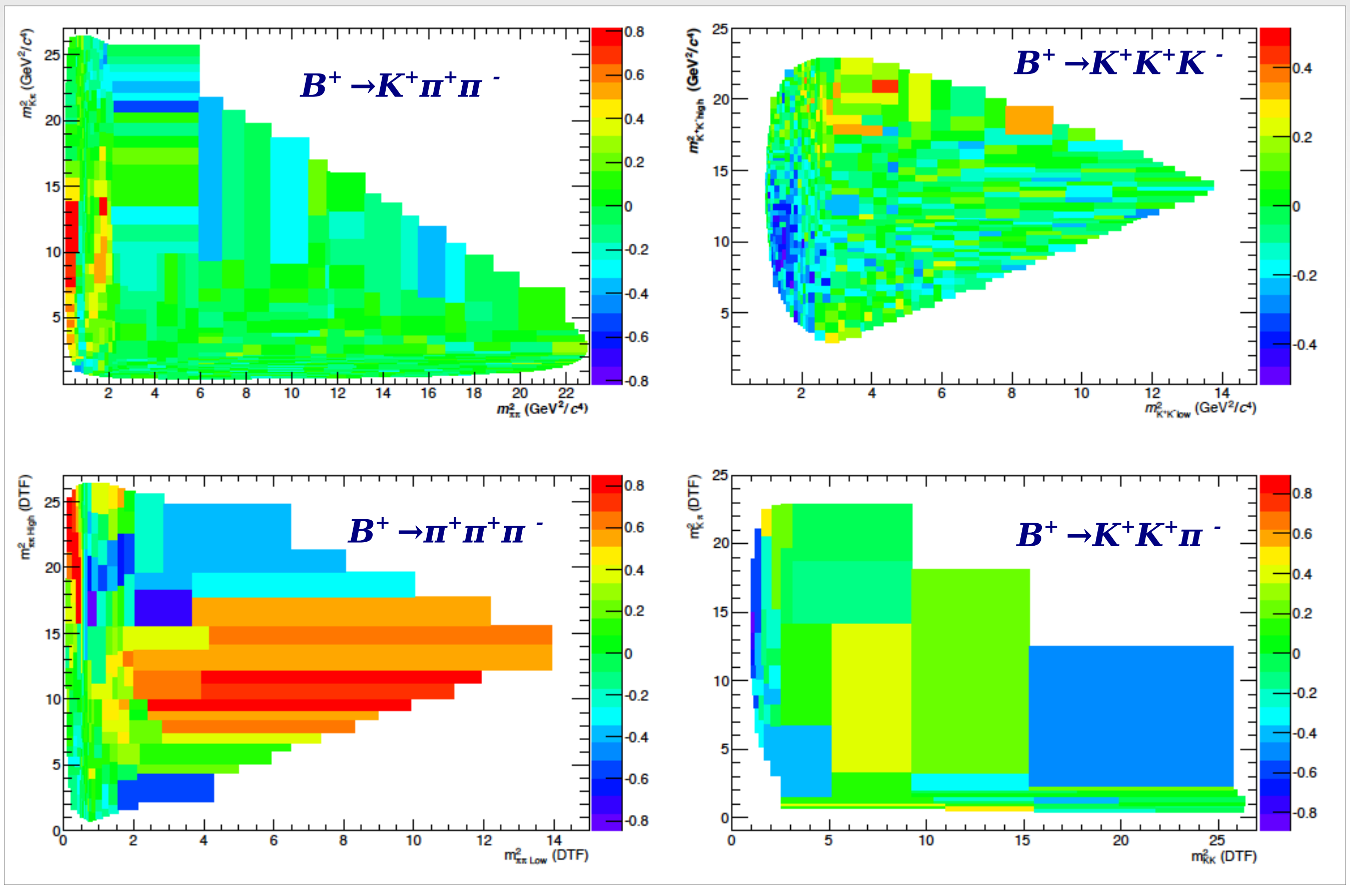
Measurements of CP violation in the three-body phase space of charmless $B^{\pm}$ decays

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

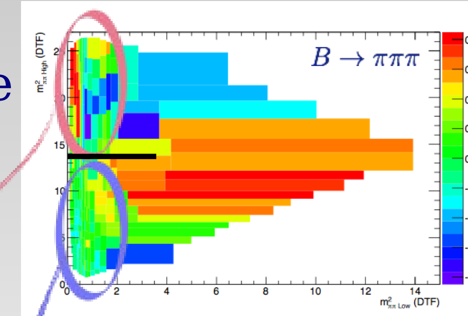
TABLE I. Signal yields of charmless three-body $B^{\pm}$ decays for the full data set.

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

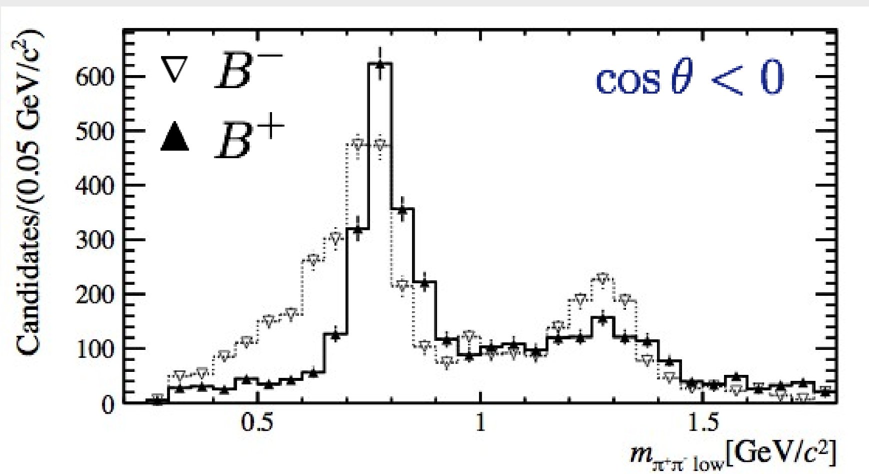
Dalitz CPV Map as a tool to understand *long distance* strong phase variations

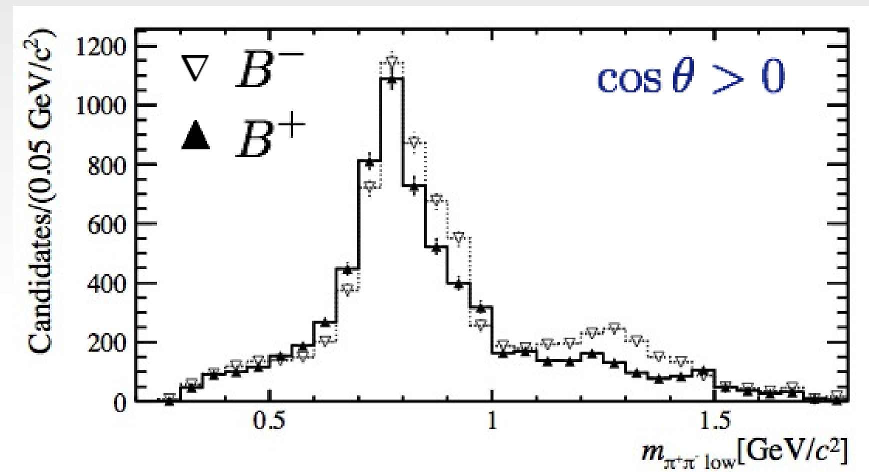


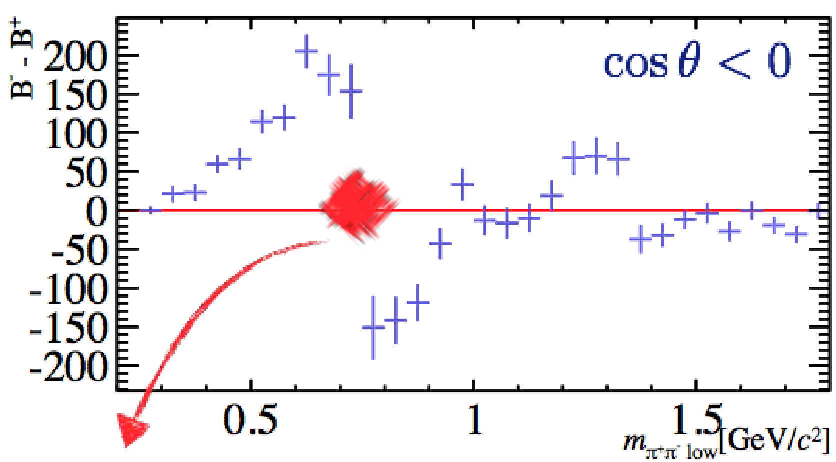
Long distance1: CP violation from S and P wave phase differences

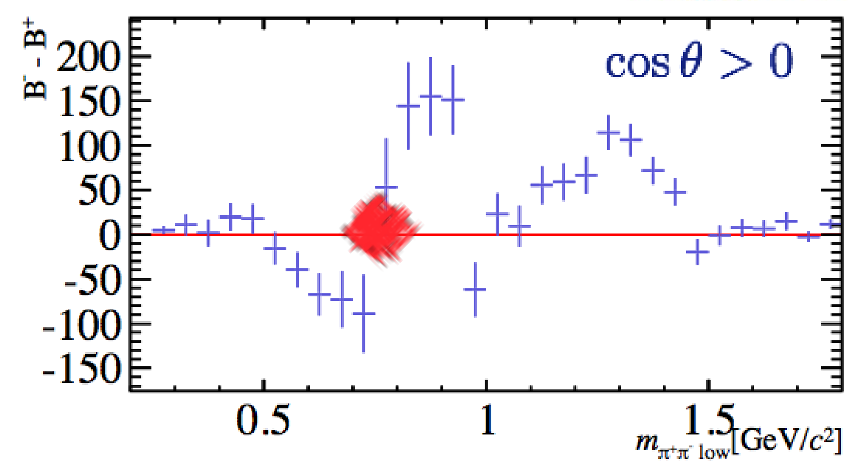


$B^{\mp} \rightarrow \pi^{\mp}\pi^{+}\pi^{-}$



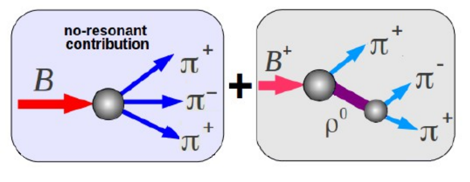






$m_{\pi\pi} \approx 770 MeV/c^2$

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



Simplest amplitude: one vector resonance and a scalar non resonant amplitudes.

B positive $\mathcal{M}_+ = a_+^\rho e^{i\delta_+^\rho} F_\rho^{\rm BW} \cos\theta + a_+^{nr} e^{i\delta_+^{nr}} F^{\rm NR}$

B negative $\mathcal{M}_- = a_-^\rho e^{i\delta_-^\rho} F_\rho^{\rm BW} \cos\theta + a_-^{nr} e^{i\delta_-^{nr}} F^{\rm NR}$

$\delta^i_+ = \delta^i_s + \Phi^i_w$

$\delta^i_- = \delta^i_s - \Phi^i_w$

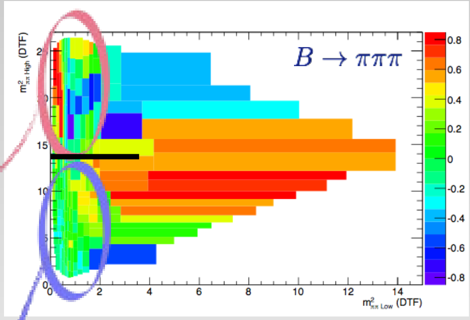
$$F_R^{\rm BW}(s) = \frac{1}{m_R^2 - s - i m_R \Gamma_R(s)}$$

$F^{NR} = 1$

θ is the Gottfried-Jackson angle to spin 1 resonances: $1 > \cos\theta > -1$

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

Long distance1: CP violation from S and P wave phase differences



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

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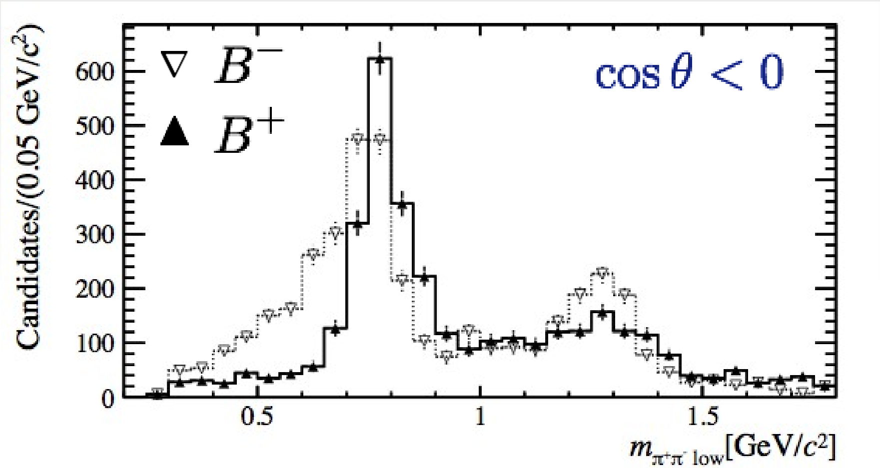
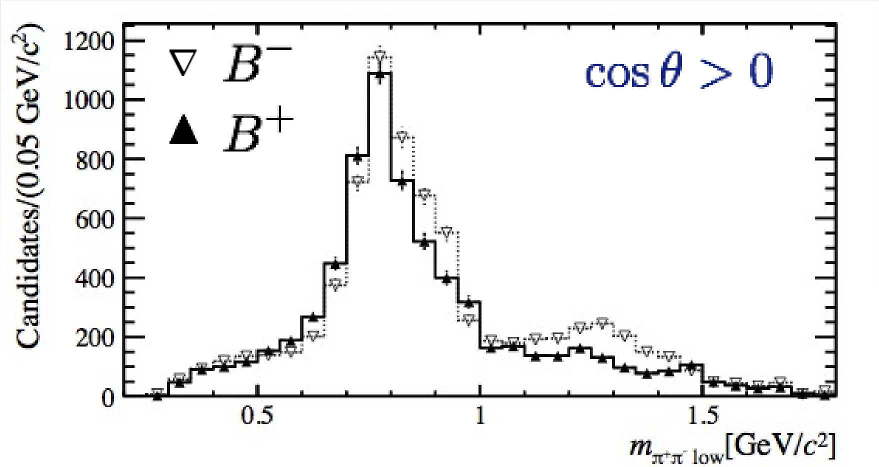
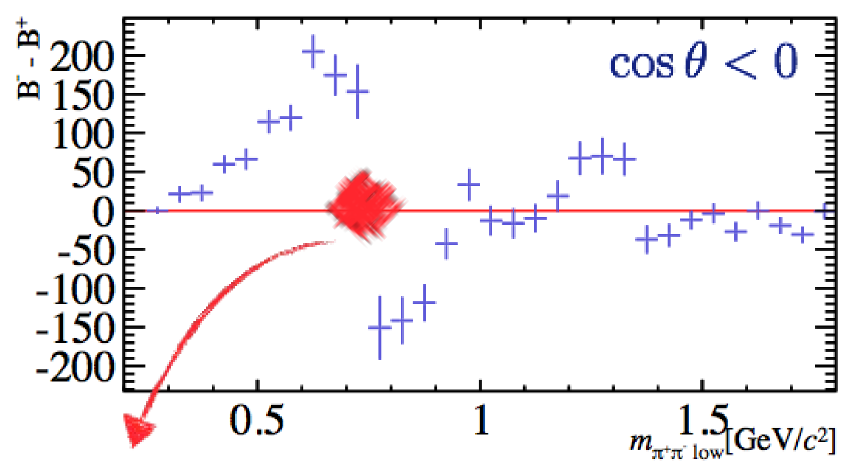
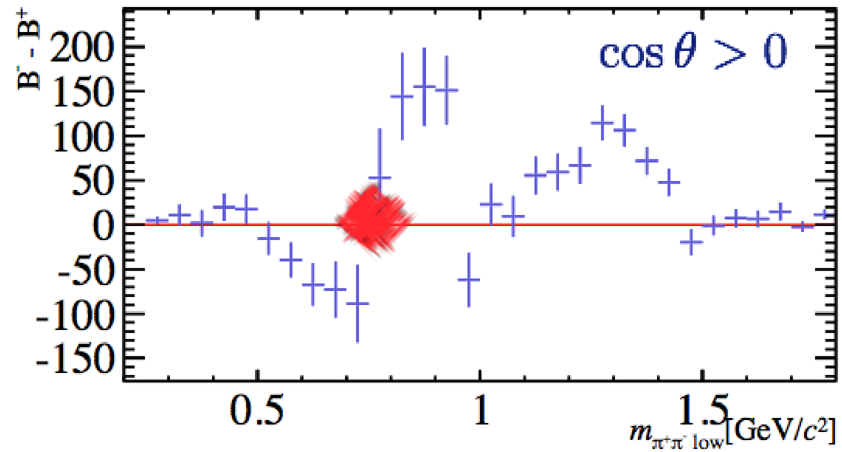




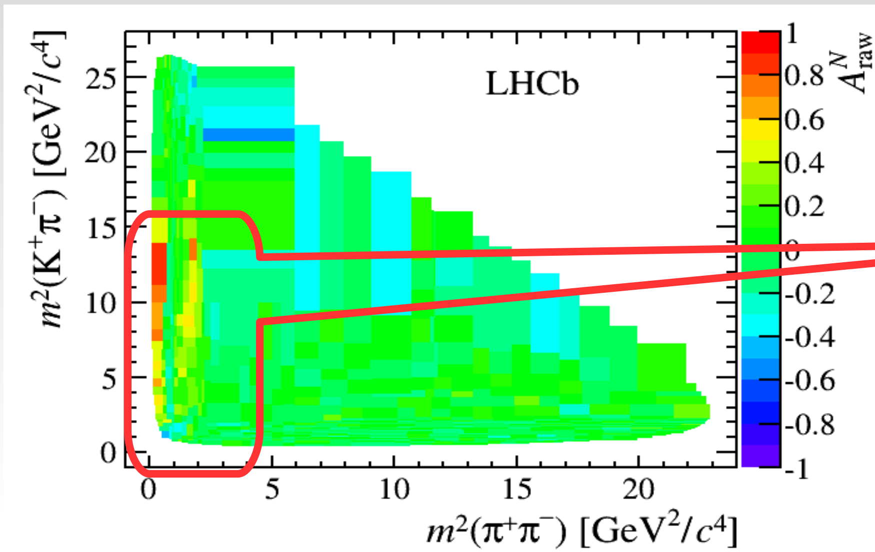


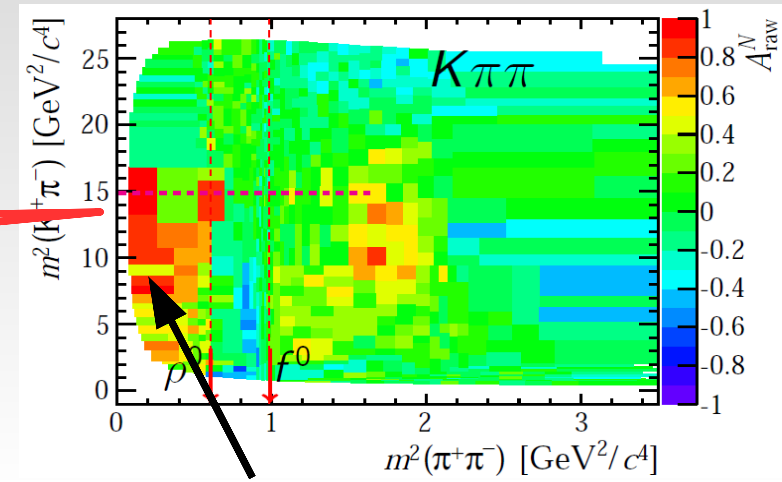


$m_{\pi\pi} \approx 770 MeV/c^2$

Long distance1: CP violation from S and P wave phase differences

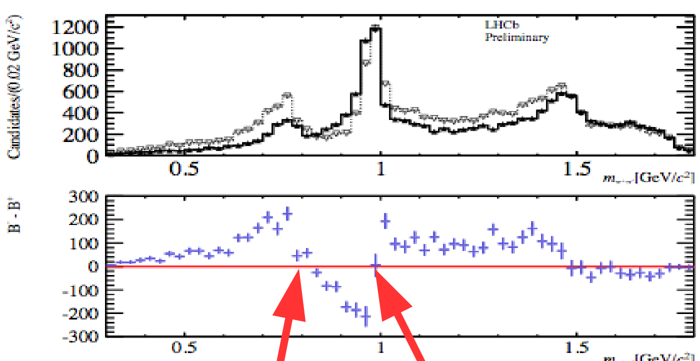
$B^{\mp} \rightarrow K^{\mp}\pi^{+}\pi^{-}$



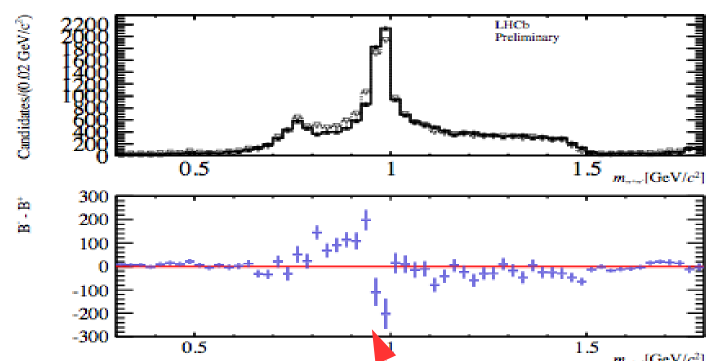


CP asymmetry close with 60%

COS Θ < 0



COS Θ > 0

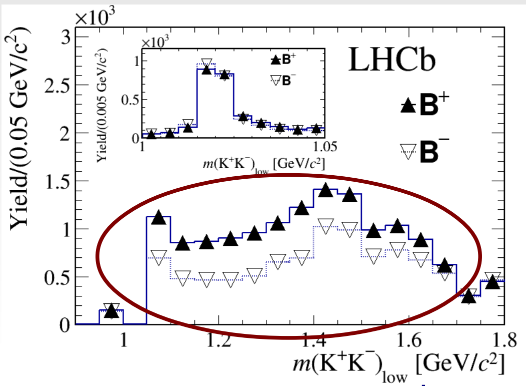


Zero around the ρ(770) and f0(980)

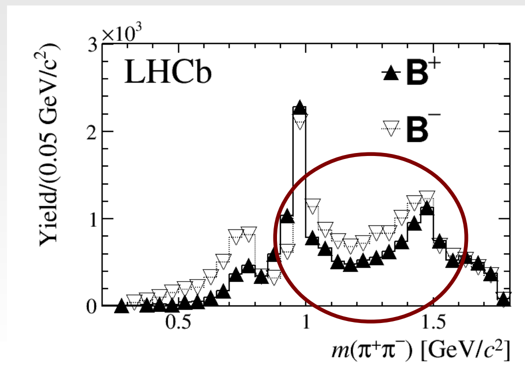
The zero around the f0(980), nothing clear around ρ(770).

Long distance2: CP violation from re-scattering : *final state interaction $\pi^+ \pi^- \rightarrow K^+ K^-$*

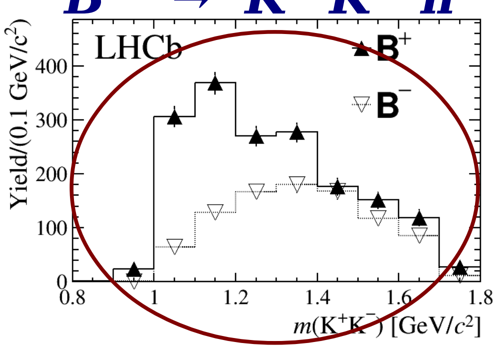
$B^{\mp} \rightarrow K^{\mp} K^+ K$



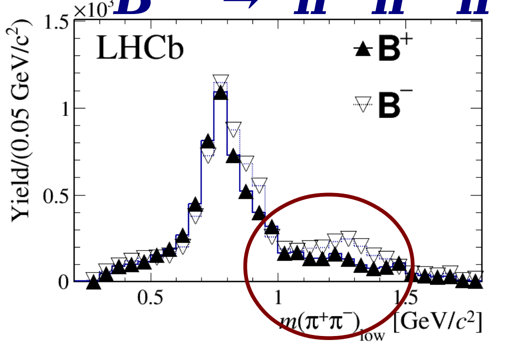
$B^{\mp} \rightarrow K^{\mp} \pi^+ \pi^-$



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



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



- positive ~~CP~~ in $B^{\mp} \rightarrow K^{\mp} \pi^+ \pi^-$ and $B^{\mp} \rightarrow \pi^{\mp} \pi^+ \pi^-$
- negative in $B^{\mp} \rightarrow \pi^{\mp} K^+ K^-$ and $B^{\mp} \rightarrow K^{\mp} K^+ K^-$.
- Same invariant mass: between 1 to 1.6GeV

Cohen, D et al PRD 22 (1980) 2595

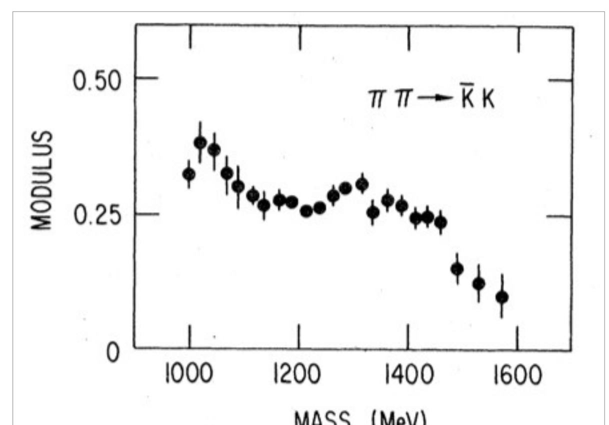


FIG. 27. Modulus of the $\pi\pi \rightarrow \bar{K}K$ scattering amplitude $|T(\pi\pi \quad \bar{K}K)|$ from solution I(b).

C̸P violation and the CPT Theorem

CP violation → presence of weak phase

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

- C̸P violation ⇒ *p.ex.* $\Gamma_1 (M^+ \rightarrow f^+_1) > \Gamma_1 (M^- \rightarrow f^-_1)$.
- CPT conservation ⇒ Sum of the partial width from particle and anti-particle must be the same:

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

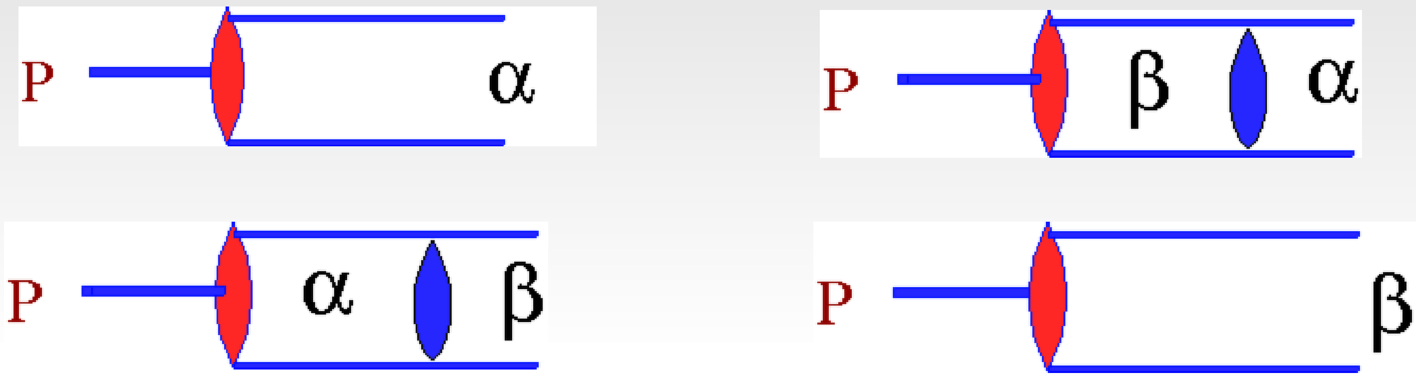
Exact symmetry ⇒ exact proportion: so it can not be assumed by chance

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

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

Wolfenstein (**Phys.Rev. D43 (1991) 151-156)** ***and Bigi's book***

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



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

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

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

$$<\bar{\alpha} \,|\, T \,|\, \bar{P}> = e^{i\delta\alpha} [\, T^*_\alpha + i t_{\alpha\beta} T^*_\beta]$$

$$<\bar{\beta} \,|\, T \,|\, \bar{P}> = e^{i\delta\beta} [\, T^*_\beta + i t_{\alpha\beta} T^*_\alpha]$$

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

Wolfenstein (**Phys.Rev. D43 (1991) 151-156)** *and Bigi's book*

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:

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

T(P -> a) = exp(i ∫a) [Ta +∑aj≠a Taj i Taj,aresc] *

T(P̄ -> ā) = exp(i ∫a) [T*a +∑aj≠a T*aj i Taj,aresc]

∫ B(a)=|T(P -> a)|2-|T(P̄ -> ā)|2=4∑aj≠a Taj,aresc ImT*aTaj

Without strong re-scattering *direct* CP asymmetries can*not* happen, *even if there are weak phases.*

Misha & Misha & collab.; Wolfenstein

The goal: measuring CP asymmetries probes *existence* & even *features* of New Dynamics (ND): they can depend only an ~~amplitude.~~

∫ B(a)=|T(P -> a)|2-|T(P̄ -> ā)|2=4∑aj≠a Taj,aresc ImT*a Taj

Ikaro's presentation

There are tools to deal with much more & `complex' data:

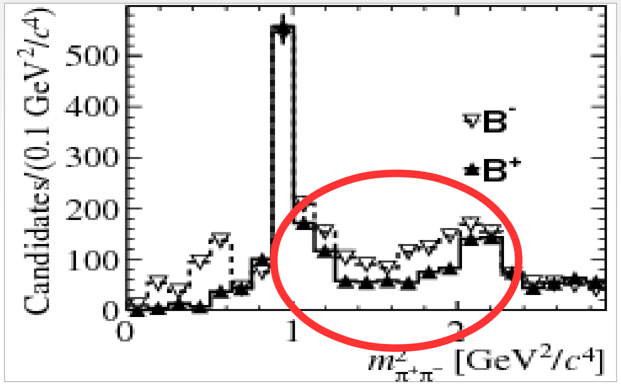
-- unitary
-- chiral symmetry: pions [+++], kaons [++/+],
-- dispersion relations …
-- fitting the data is the 2nd step, but not the final one!

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

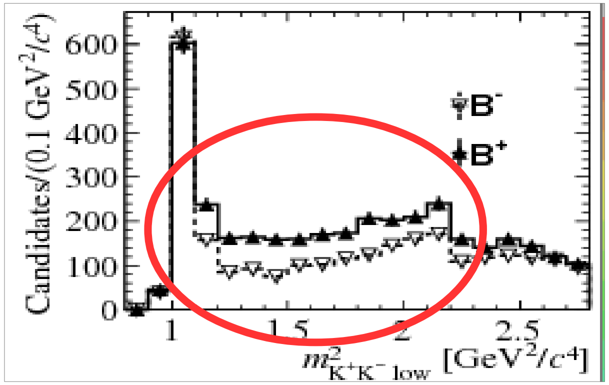
I. B., T. Frederico and O. Lourenço Phys. Rev. D 89, 094013 (2014)-

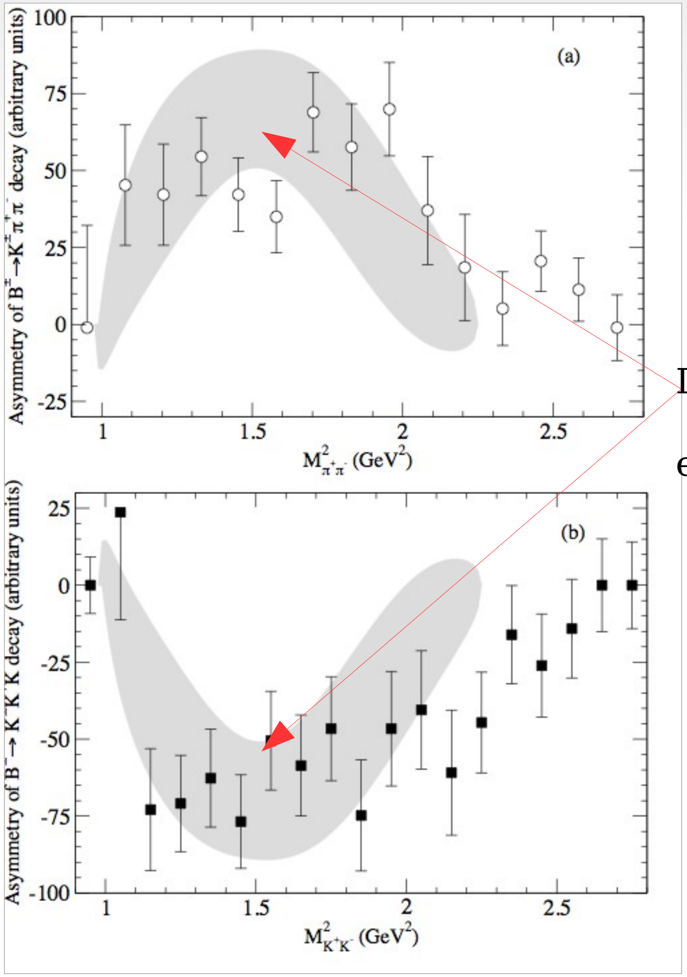
Only 2011 data

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



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





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

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

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

Putting together re-scattering and S and P interference in Run I data

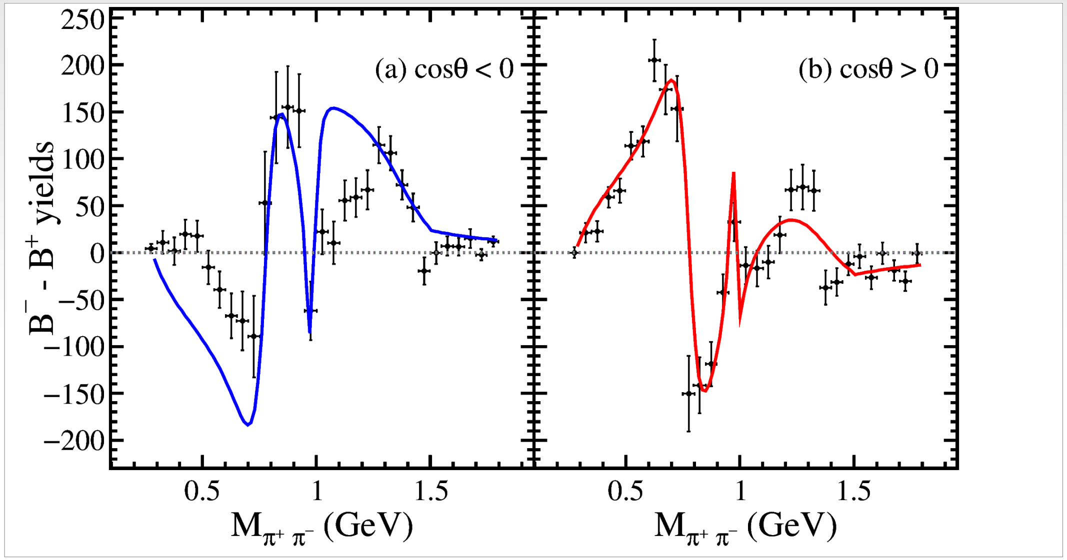
CP violation in $B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$ and $B^{\mp} \to \pi^{\mp}K^{+}K^{-}$ Decays

J.H. Alvarenga Nogueira, I. B., A.B.R. Cavalcante, T. Frederico, O. Lourenço. Phys.Rev. D92 (2015) 5, 054010.

Coupling channels, one dimensional analysis with CPT constraint

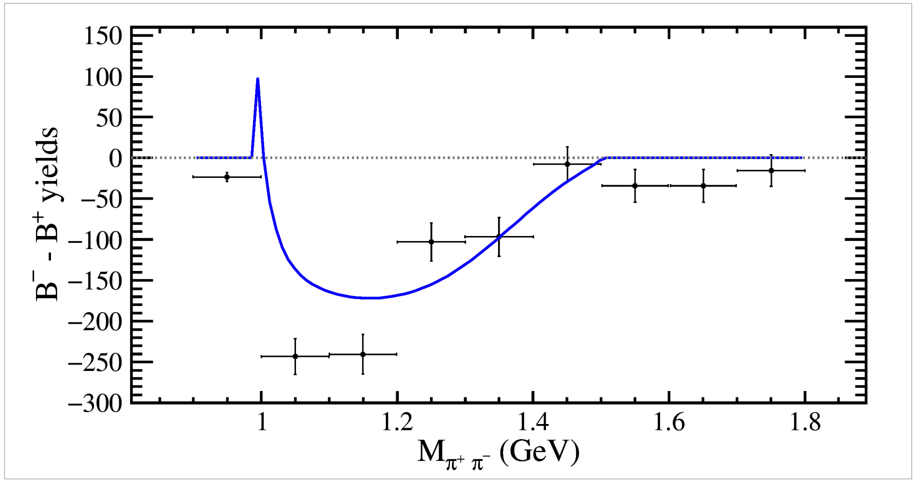
$B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$

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

J.H. Alvarenga Nogueira, I. B., A.B.R. Cavalcante, T. Frederico, O. Lourenço. Phys.Rev. D92 (2015) 5, 054010.

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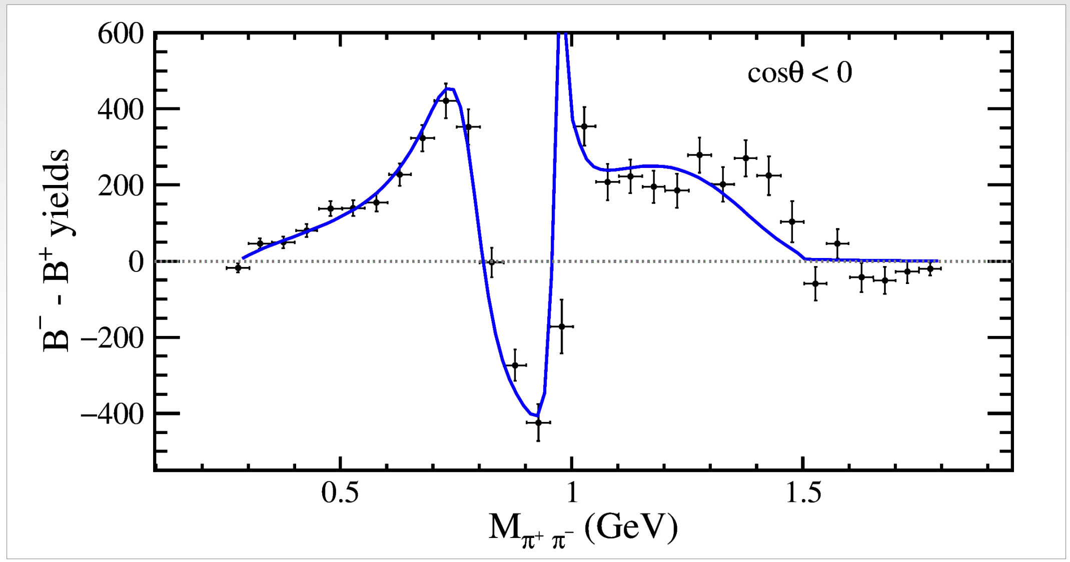
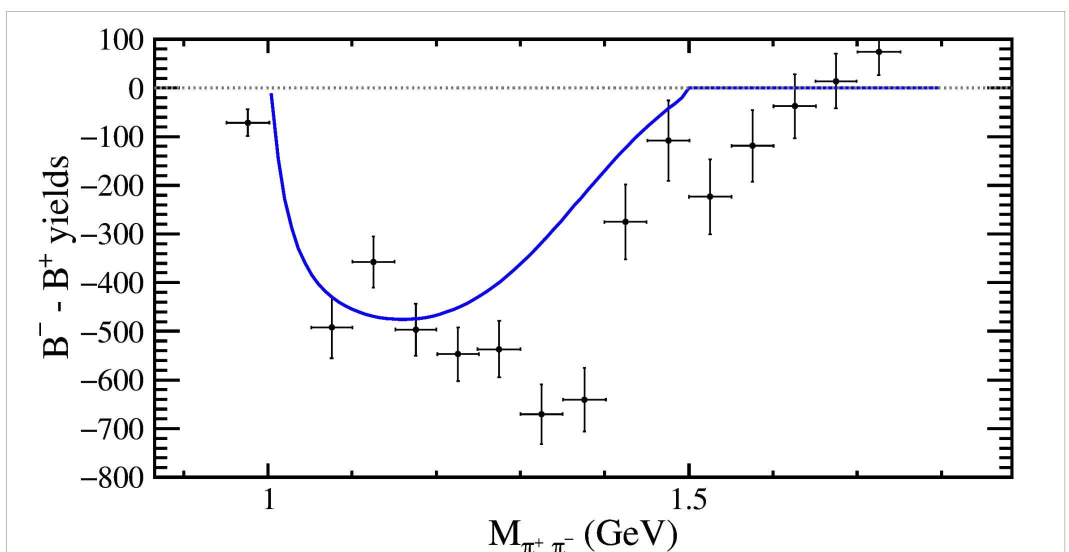


$B^{\mp} \rightarrow K^{\mp}K^{+}K^{-}$

Re-scattering $\pi^{+}\pi^{-} \rightarrow K^{+}K^{-}$



Importance of CPT constraint to CP Violation

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

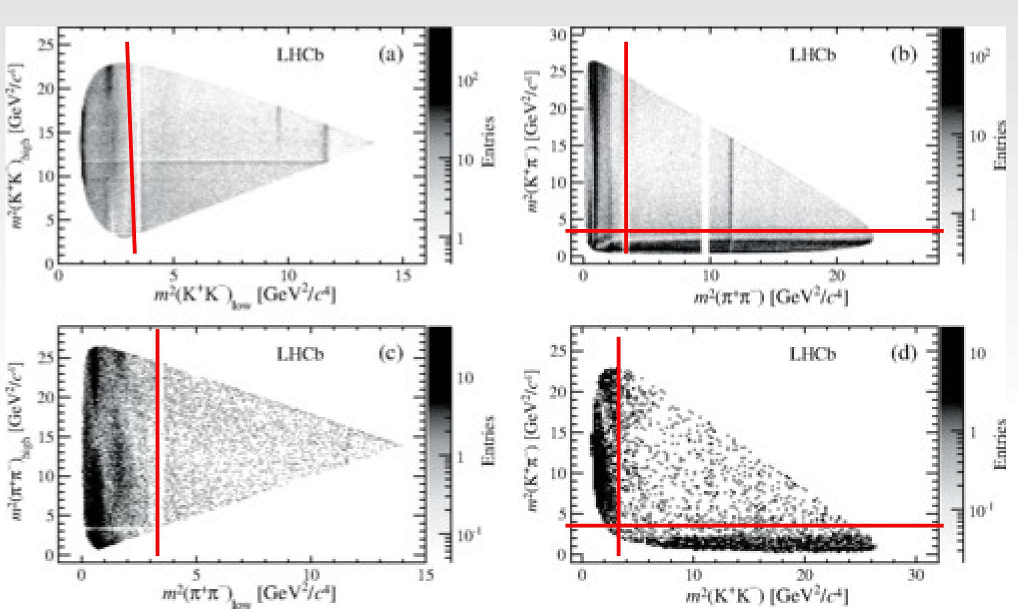
' The CKM suppressed weak decays for beauty hadrons produce FS with more hadrons than two, three & four ones. Therefore one expects that **CPT invariance is not a "practical" tool in *beauty decays*** '

In fact, p.ex. the $B^+ \to K^+ \pi^+ \pi^-$ can have many B decay channels with accessible through 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 $M^2_{h+h-} < 3.0 GeV^2$ dominated by low mass resonances***

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

Assuming 2 +1 approximation, that is the bachelor as a spectator:

we can use hadron-hadron elastic scattering as a source of the FSI

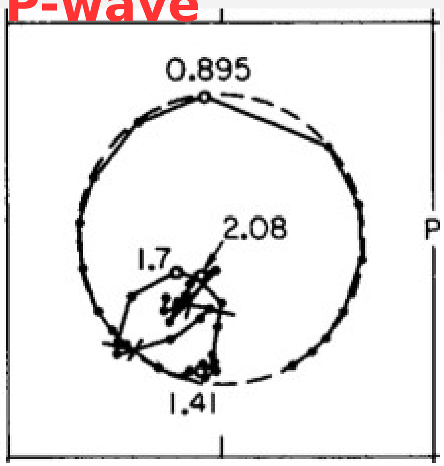
Elastic scattering: $K^+\pi^- \to K^+\pi^-$

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

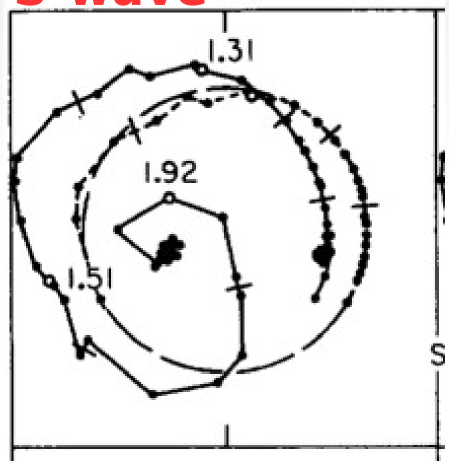
LASS collaboration $K^+\pi^- \to K^+\pi^-$ (1988)

Nuclear Physics B296 (1988) 493–526

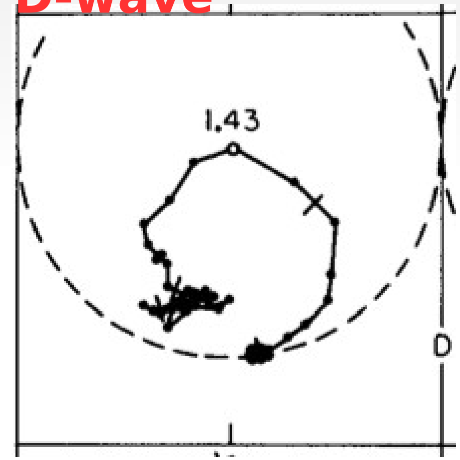
P-wave



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 and P waves in the unitary circle below 1 GeV.

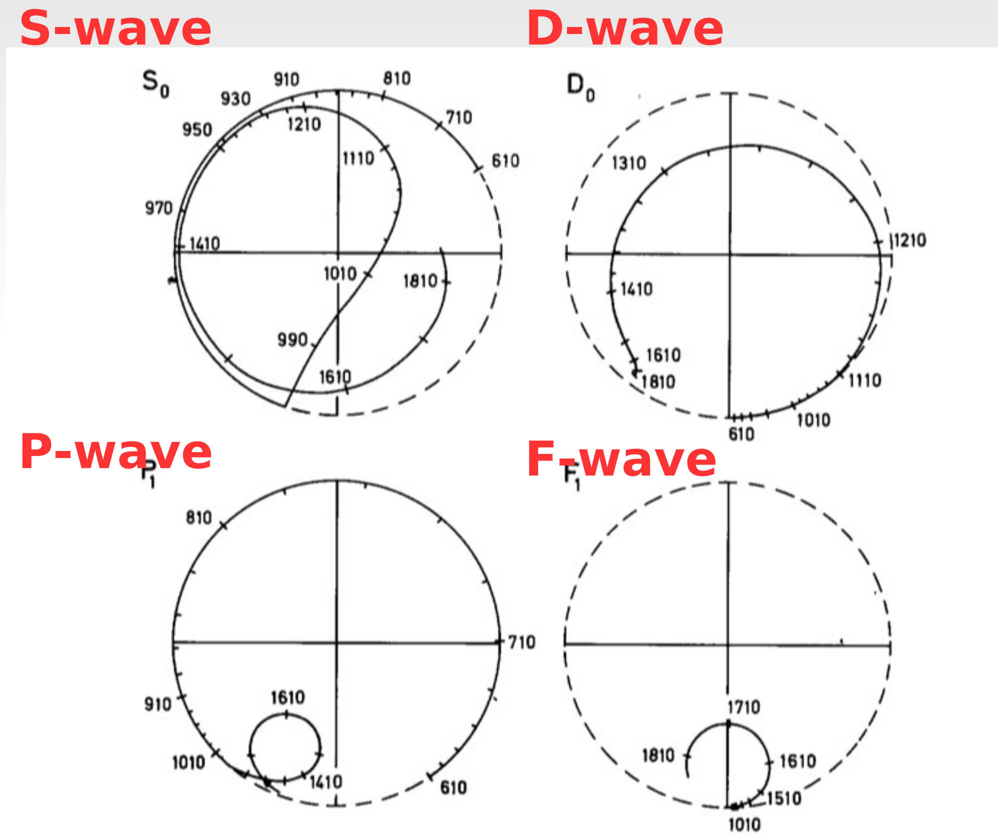
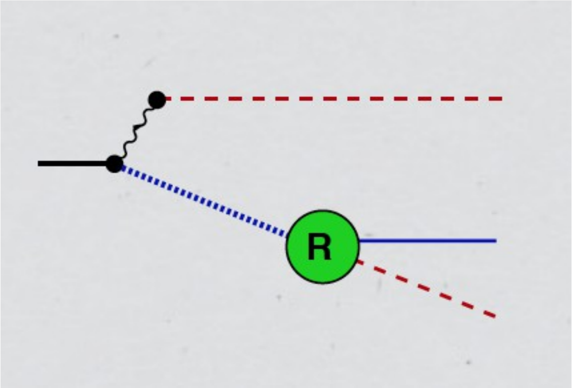


Fig. 6. Argand diagrams (Im T_l^I *versus* Re T_l^I) for the partial wave amplitudes from the energy-dependent fit. Numbers indicate the $\pi\pi$ energy.

CP and CPT constraint in three body B decays

Assuming 2 + 1 approach approximation with the non-interacting bachelor



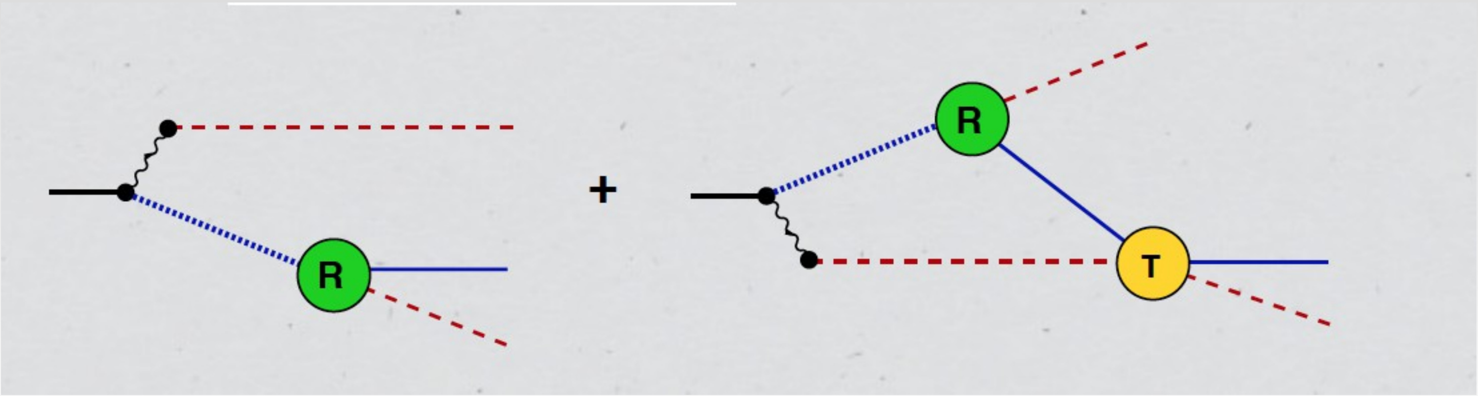
CPT does not allow directly CP violation in B→ h R with m_R <1Gev

Like the CPT constraint to possible CP violation

$$K^+ \rightarrow \pi^+ \pi^0$$

Theory of Weak Interactions in Particle Physics. Robert E. Marshak, Riazuddin, and Ciaran P. Ryan. Wiley-Interscience, New York, 1969

CP violation is only possible with the participation of the bachelor interacting with the three body system.



- ***If one observe CP violation in these channels, imply the presence of second order interaction in three body decays.***

Practical consequences coming from high order hadronic interaction:

- *Watson's theorem can not be apply easily*
- *The loop introduce a new strong phase*
- *The resulting resonance mass and width can be shifted (I. B, P.Magalhães.arXiv:1512.09284 [hep-ph]).*
- *Isobar model, K-matrix, "LASS parametrisation" and etc.. must be re-thinking*
- *Isobar can changing the resonance mass and width or even add a new three body amplitude.*

PDG list of Directly CPV involving low mass resonances $B \to R\ p$

CPV in $B^{\mp}$ decays

$A_{CP}(B^+ \to \eta' K^*(892)^+) = -0.26 \pm 0.27$

$A_{CP}(B^+ \to \eta K^*(892)^+) = 0.02 \pm 0.06$

$A_{CP}(B^+ \to \omega K^+) = -0.02 \pm 0.04$

$A_{CP}(B^+ \to K^{*0}\pi^+) = -0.04 \pm 0.09$

$A_{CP}(B^+ \to K^*(892)^+ \pi^0) = -0.39 \pm 0.21$

$A_{CP}(B^+ \to f(980)^0 K^+) = -0.08 \pm 0.09$

$A_{CP}(B^+ \to \rho^0 K^+) = 0.37 \pm 0.10$

$A_{CP}(B^+ \to K^0\rho^+) = -0.03 \pm 0.15$

$A_{CP}(B^+ \to \varphi K^+) = 0.024 \pm 0.028$

$A_{CP}(B^+ \to \rho^0\pi^+) = 0.18 \pm 0.09$

$A_{CP}(B^+ \to \rho^+\pi^0) = 0.02 \pm 0.11$

$A_{CP}(B^+ \to \omega\pi^+) = -0.04 \pm 0.06$

$A_{CP}(B^+ \to \eta\rho^+) = 0.11 \pm 0.11$

$A_{CP}(B^+ \to \eta'\rho^+) = 0.26 \pm 0.17$

CPV in B^0 decays

$A_{CP}(B^0 \to \eta K^*(892)^0) = 0.19 \pm 0.05$

$A_{CP}(B^0 \to \rho^- K^+) = 0.20 \pm 0.11$

$A_{CP}(B^0 \to K^*(892)^+ \pi^-) = -0.22 \pm 0.06$

(-0.308 ± 0.062 LHCb PRL 120, 261801 (2018))

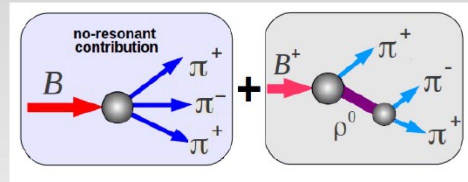
$A_{CP}(B^0 \to K^{*0}\pi^0) = -0.15 \pm 0.13$

$A_{CP}(B^0 \to \rho^+\pi^-) = 0.13 \pm 0.06$

$A_{CP}(B^0 \to \rho^-\pi^+) = -0.08 \pm 0.08$

Model Independent Method to extract ACP in B → PV decays

J. H. Alvarenga Nogueira, I. B, T. Frederico, P.C. Magalhães, J. Molina Rodriguez. Phys.Rev. D94 (2016) no.5, 054028.



Simplest amplitude: one vector resonance and a scalar non resonant amplitudes.

B positive $\mathcal{M}_+ = a_+^\rho e^{i\delta_+^\rho} F_\rho^{\rm BW} \cos\theta + a_+^{nr} e^{i\delta_+^{nr}} F^{\rm NR}$

B negative $\mathcal{M}_- = a_-^\rho e^{i\delta_-^\rho} F_\rho^{\rm BW} \cos\theta + a_-^{nr} e^{i\delta_-^{nr}} F^{\rm NR}$

$\delta^i_+ = \delta^i_s + \Phi^i_w$

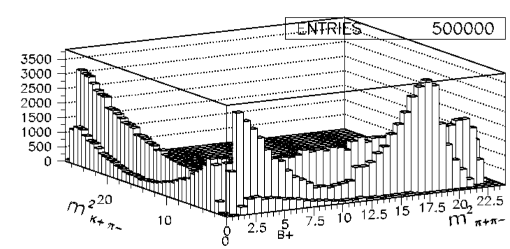
$\delta^i_- = \delta^i_s - \Phi^i_w$

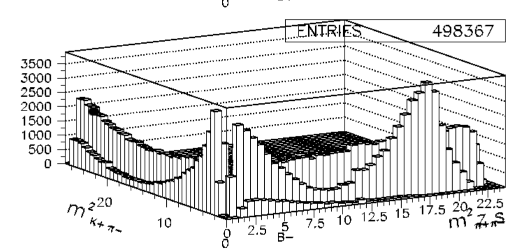
$$F_R^{\rm BW}(s) = \frac{1}{m_R^2 - s - i m_R \Gamma_R(s)}$$

$F^{NR} = 1$

θ is the Gottfried-Jackson angle to spin 1 resonances: COS θ change from **-1 to +1**
and it is assumed it depend only to the transversal Dalitz variable around the vector resonance mass

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





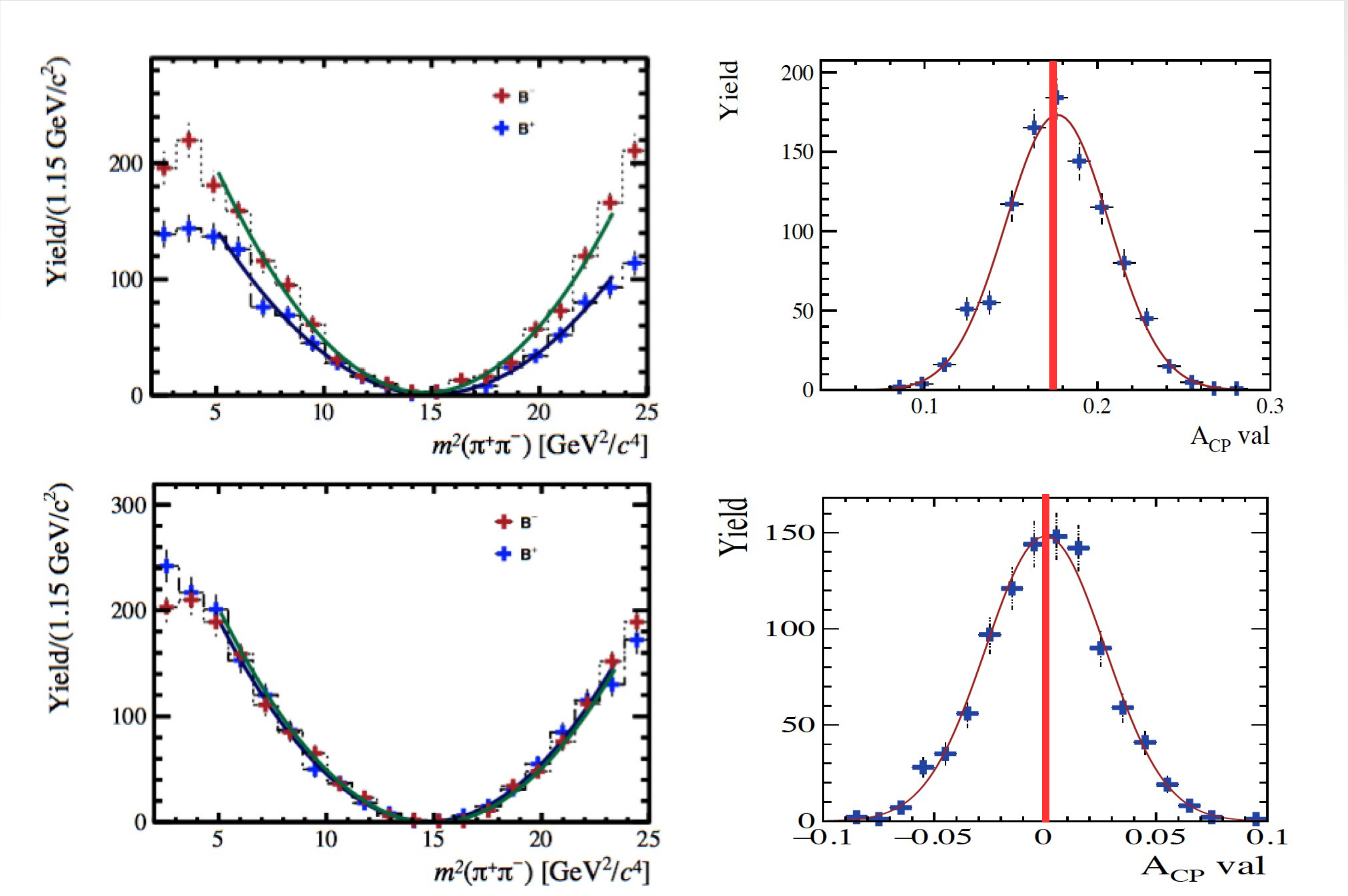
Low mass vector meson is in general close to a scalar one,
sharing the same region of the phase space

Toy simulation to test method to extract ACP in $B \rightarrow PV$ decays

Simulation with 1000 samples, 20,000 events each

Simulation of $B^{\mp} \rightarrow \pi^{\mp}\pi^{+}\pi^{-}$ with BaBar fit parameters:
Acp ($B^{\mp} \rightarrow \pi^{\mp}\rho^{0}$) =18%

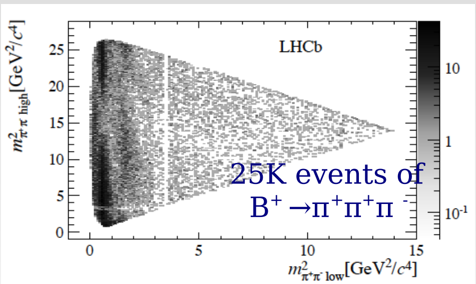
Simulation of $B^{\mp} \rightarrow \pi^{\mp}\pi^{+}\pi^{-}$ with BaBar fit parameters:
Acp ($B^{\mp} \rightarrow \pi^{\mp}\rho^{0}$) = 0%



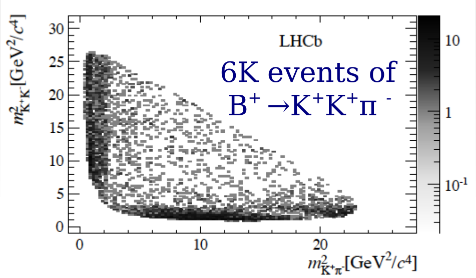
LAURA++ fit result:
0.177± 0.03 and 0.00 ± 0.03

Near Future

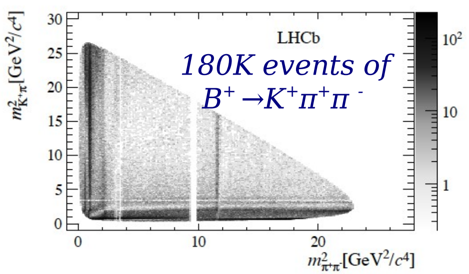
B decays Amplitude Analysis on going with run1 data.



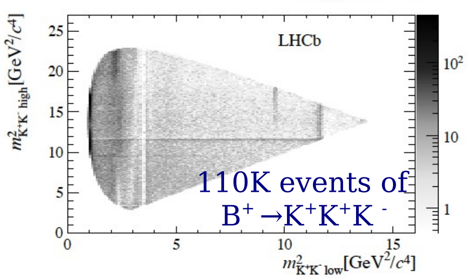
$B^{\mp} \rightarrow \pi^{\mp}\pi^{+}\pi^{-}$: Analysis under collaboration review partially will be presented by Jussara in a few minutes



$B^{\mp} \rightarrow K^{\mp}K^{+}\pi^{-}$: will be presented preliminary results in a few minutes by the first time by Jussara

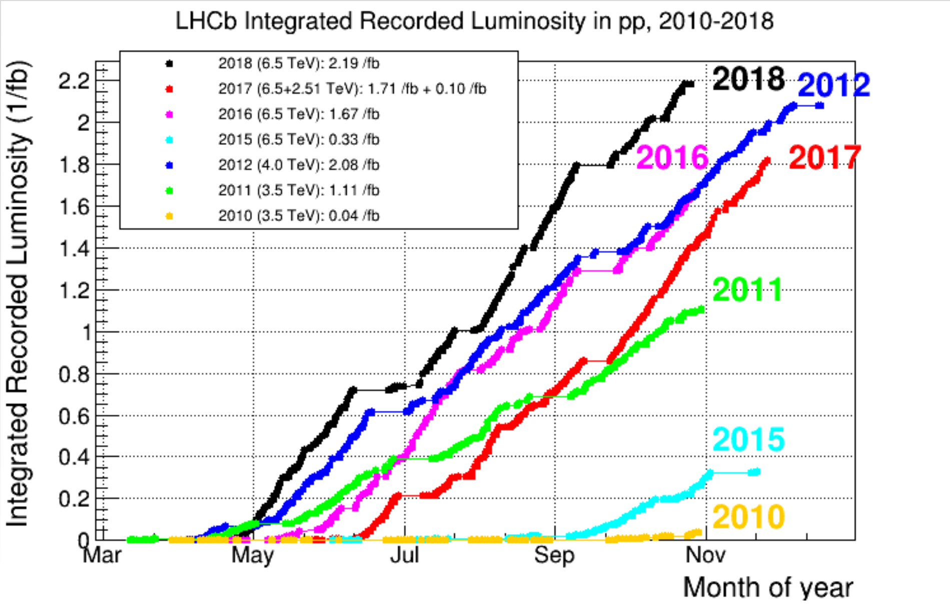


$B^{\mp} \rightarrow K^{\mp}\pi^{+}\pi^{-}$: Analysis on going



$B^{\mp} \rightarrow K^{\mp}K^{+}K^{-}$: Analysis on going

LHCb Recorded Luminosity Run I and II and B→ hhh Yields

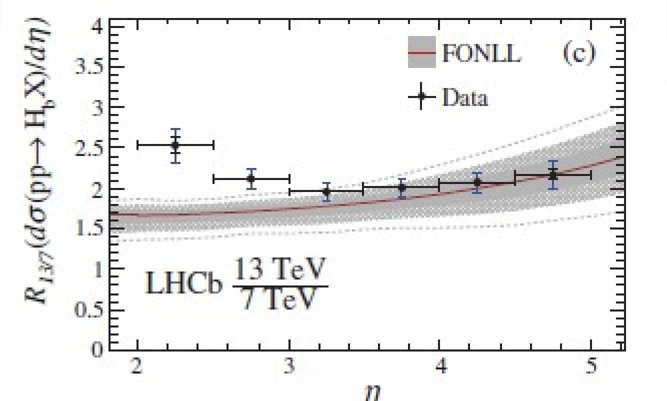


Recorded Luminosity:

Run I 2010-2012 = 3ft^{-1}

Run II 2015-2018 ~ 6ft^{-1}

Relative bb cross section
13TeV/7TeV~2



Five times more events: Run I plus Run II

Yields Run1

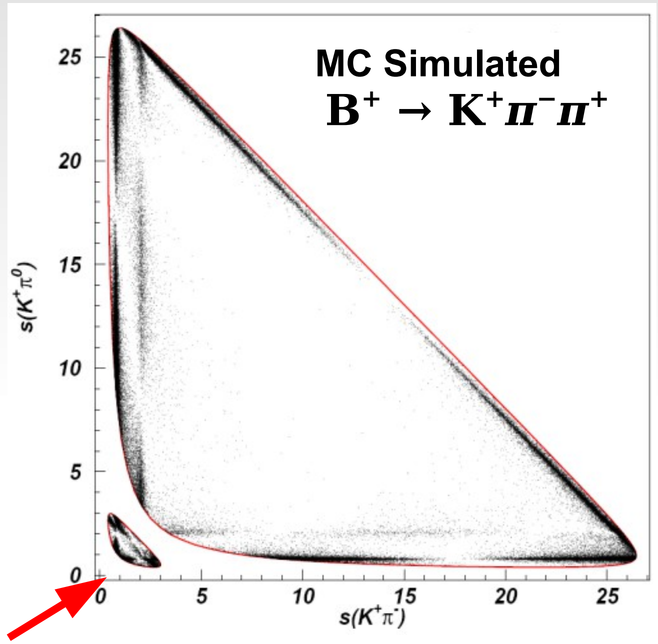
- *180K events of $B^+ \to K^+\pi^+\pi^-$*
- 110K events of $B^+ \to K^+K^+K^-$
- 25K events of $B^+ \to \pi^+\pi^+\pi^-$
- 6K events of $B^+ \to K^+K^+\pi^-$

Yields Run2 (minimum)

- *720K events of $B^+ \to K^+\pi^+\pi^-$*
- 440K events of $B^+ \to K^+K^+K^-$
- 100K events of $B^+ \to \pi^+\pi^+\pi^-$
- 24 K events of $B^+ \to K^+K^+\pi^-$

Perspective of charmless B meson decay

Phase space difference
Charm to Botton

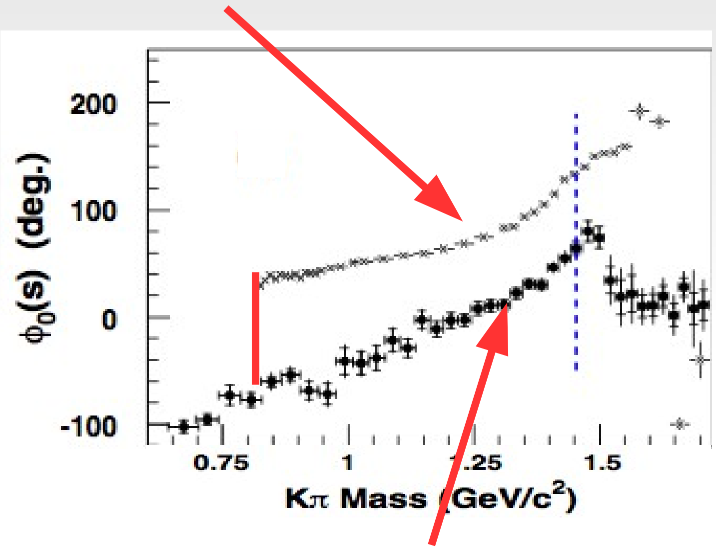


$D^0 \to K^0\pi^+\pi^+$

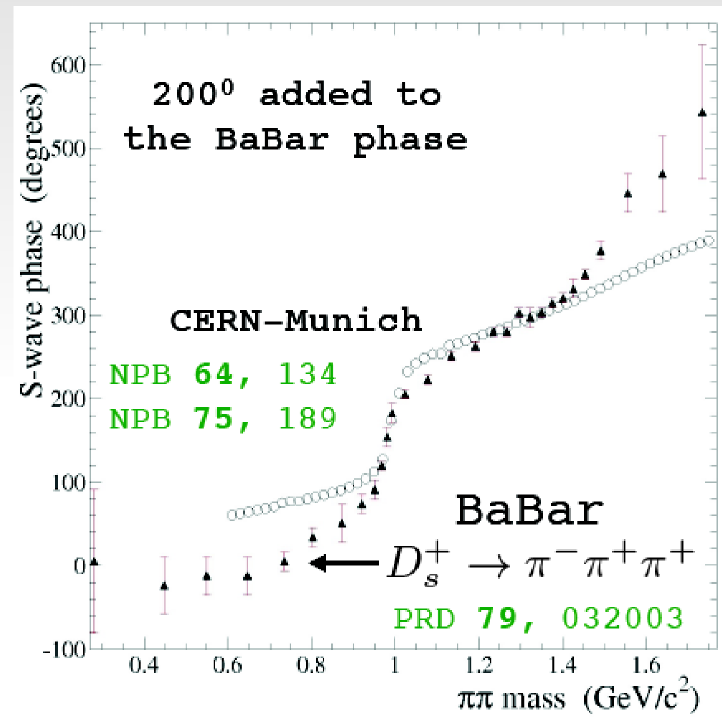
- **The big different phase space with high statistics put new questions, over the known we got on charm decays**

Does the Watson theorem is a good approximation in these decays?

$K\pi^+$ elastic scattering from LASS collaboration
NPB 296(1988)493



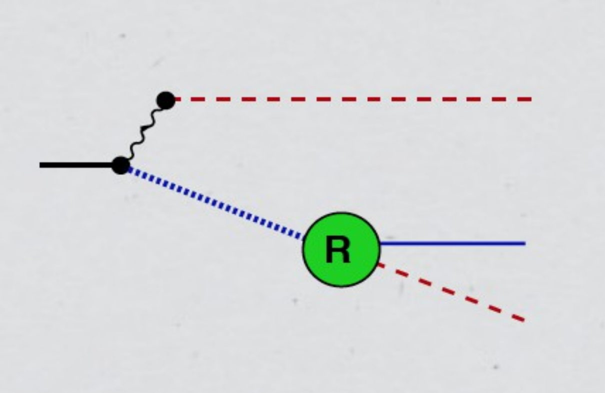
$K^-\pi^+$ scattering from $D^+ \to K^-\pi^+\pi^+$ *decay*
E791 PRD 74 (2006) 059901



Overall difference and different dependence in S, between elastic scattering decays and three body D decay

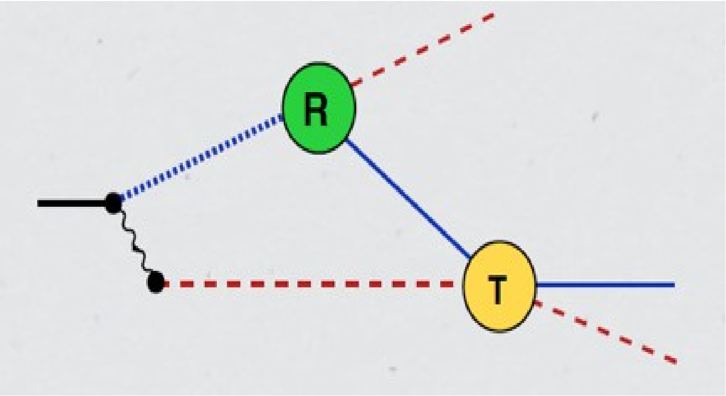
Seems that Watson theorem does not work in this decays.

Does the two body magnitudes and phases are the same in all phase space?



2 + 1 approximation imply in a constant magnitude and phase parameters for all phase space: $\mathbf{a_R\, e^{i\,\delta R}}$

Three body re-scattering



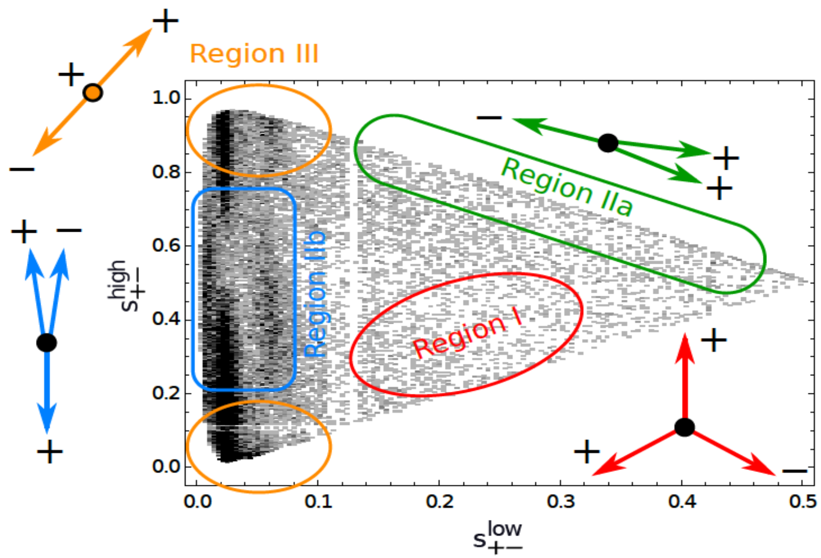
- How big could be this type of contribution ?
- $a_R\, e^{i\,\delta R} \rightarrow a_R(s)\, e^{i\,\delta(s)}$

Does the phase space can be describe for a single formalism?

Keri Vos – LHCb Seminar

S. Kränk, T. Mannel and J. Virto Nucl.Phys. B899 (2015) 247-264.

- $B^+ \to \pi^+(k_1)\pi^-(k_2)\pi^+(k_3)$ Symmetric Dalitz plot



Three special kinematical configuration

Region I: s++~ s+-low ~ s++high ~ 1/3

Region IIa: s++~ 0, s+-low ~ s+-high ~ 1/2

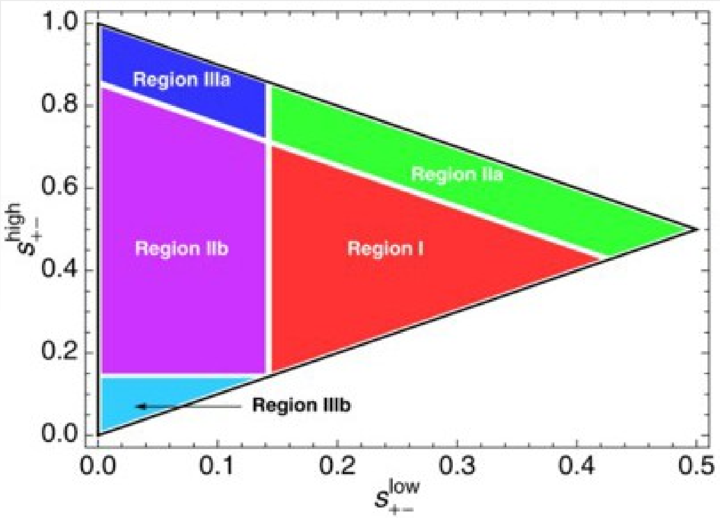
Region IIb: s+-low~ 0, s++ ~ s+-high ~ 1/2

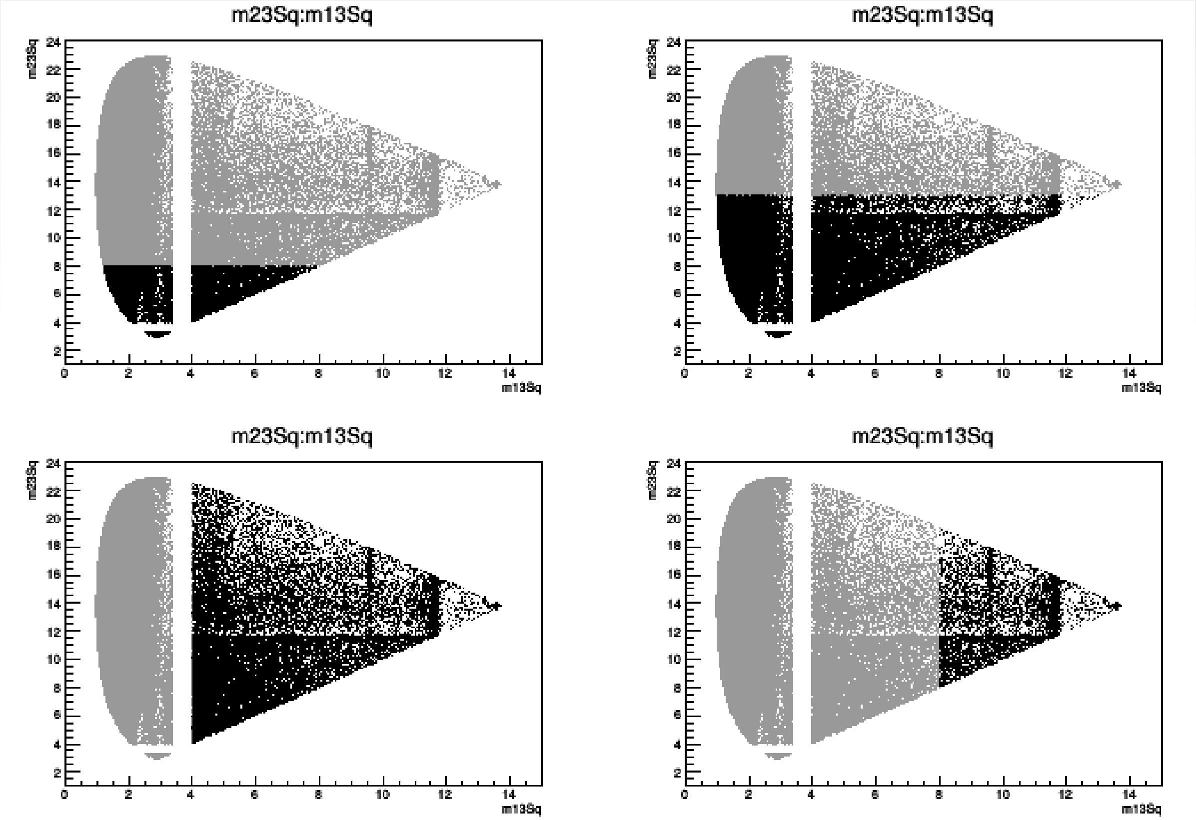
Region IIIa: s++ ~ s+-low ~ 0, s+-high~ 1

Region IIIb: s+-low ~ s+-high ~ 0, s++~ 1

Possible phase space amplitude analysis factorisation!

It is possible fit factorisation of the Dalitz plot with Laura ++ in through vetos in the following way's

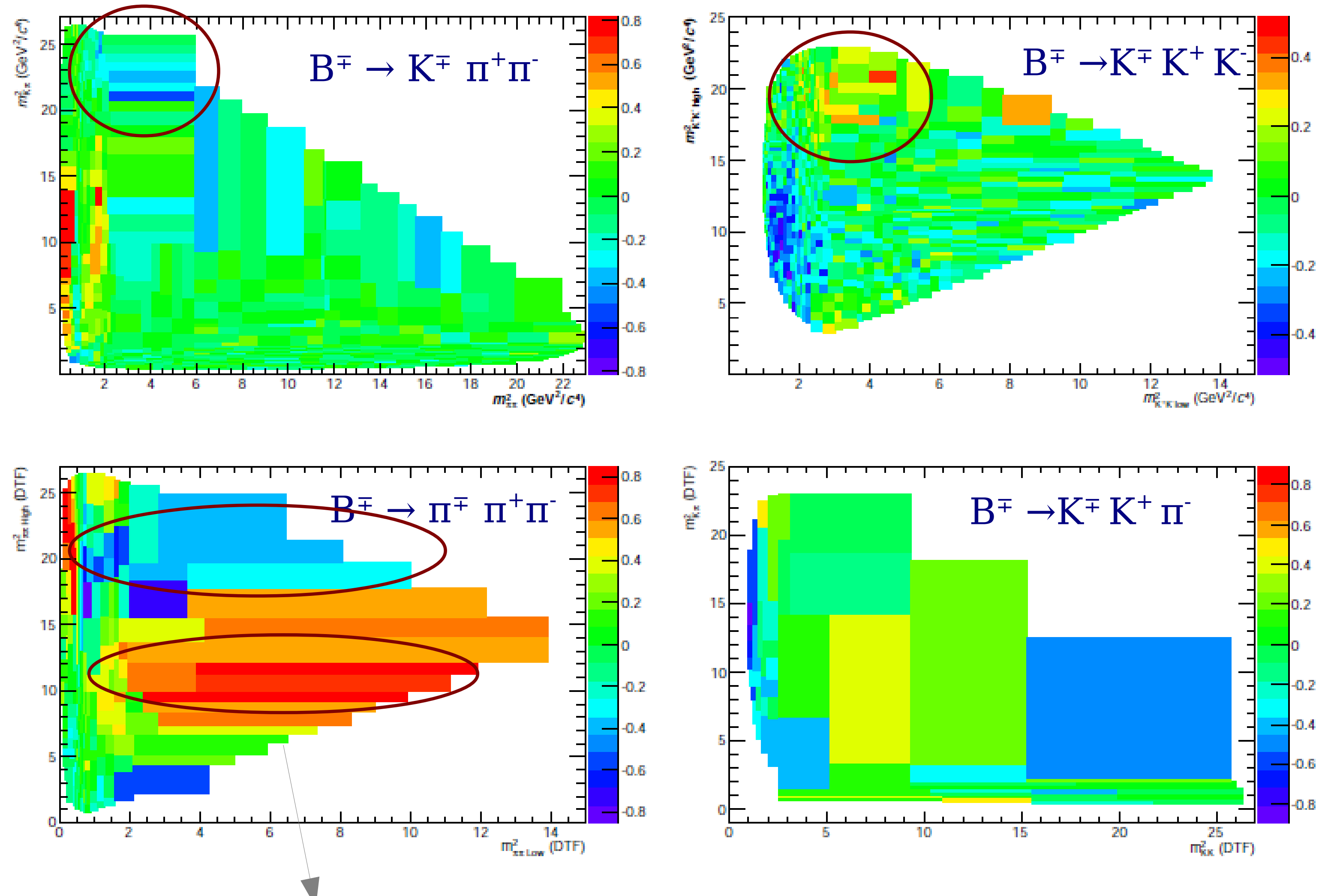




Fitting different regions Dalitz regions and confirm or not the fit parameters matching between them

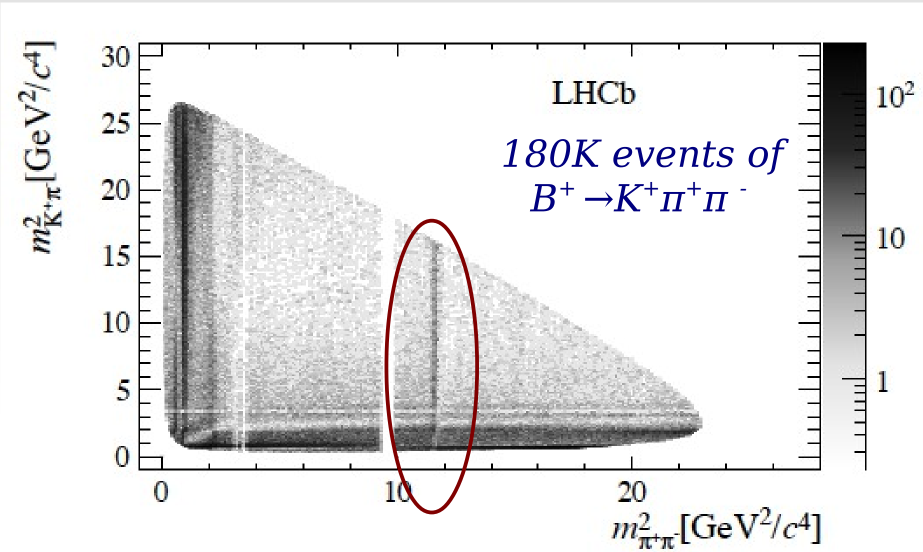
CP Dalitz distribution for the four $B^{\mp} \to h^{\mp} h^{+} h^{-}$ channels

3- $h^{+} h^{-} \to D^{+} D^{-}$ as thinking as a possibility re-scattering Wolfenstein mechanism: see Patricia's talk

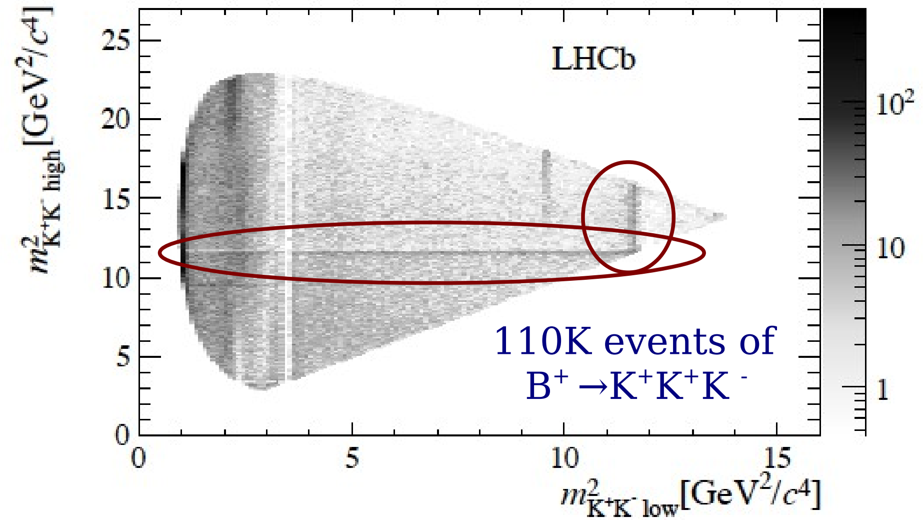


4- ??????????

Coherent sum charmonioun with light resonances: Cabibbo allowed Run I

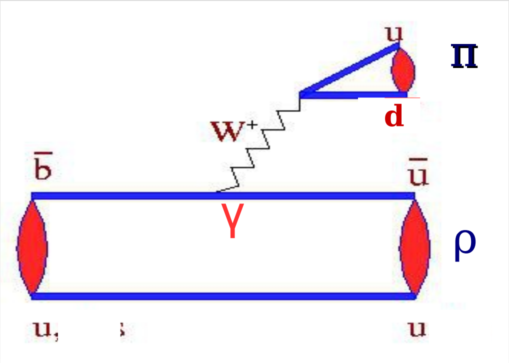


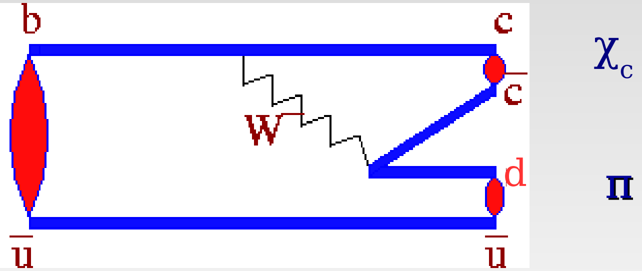
FF ($B^\mp \to K^\mp \chi_c$) and $\chi_c \to \pi^+\pi^-$
BaBar 1.29 ± 0.19 ± 0.15

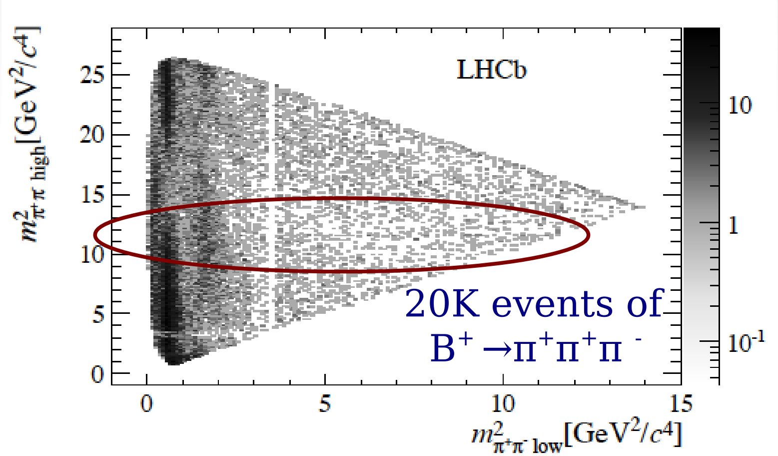


FF ($B^\mp \to K^\mp \chi_c$) and $\chi_c \to K^+K^-$
BaBar 1.12 ± 0.15 ± 0.06

Coherent sum charmonioun with light resonances: Cabibbo suppressed Run I + II

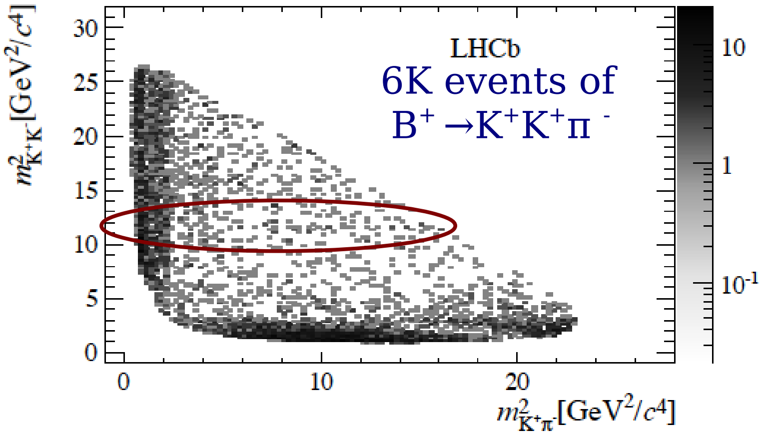






FF ($B^{\mp} \to \pi^{\mp}\ \chi_c$) and $\chi_c \to \pi^+\pi^-$

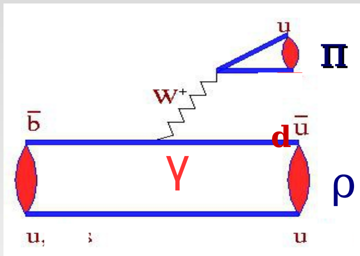
~ 500 events in LHCb run I + II

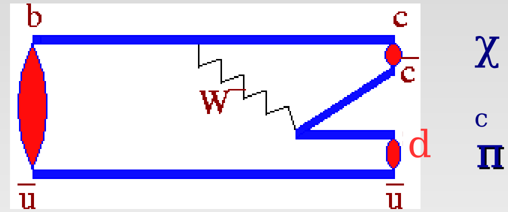


FF ($B^{\mp} \to \pi^{\mp}\ \chi_c$) and $\chi_c \to K^+K^-$

~ 300 events in LHCb run I + II

CP violation in $B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$ decay, involving charmonioum amplitude

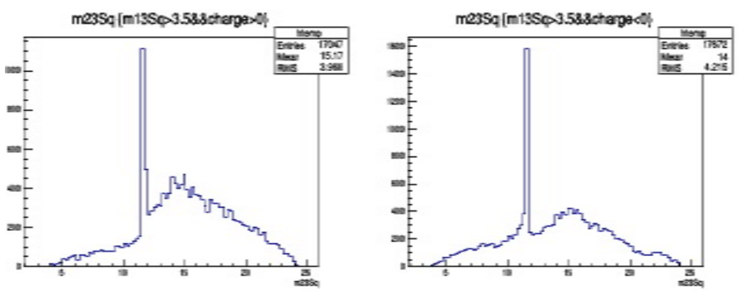


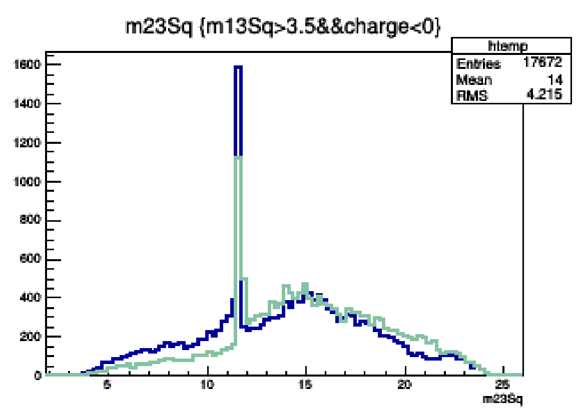


Interference between charmless amplitude, with a dominant tree component involving γ phase, with charmonioum amplitude $\pi^{\mp}\ \chi_c$ without weak phase

$B^{\mp} \to \pi^{\mp}\pi^{+}\pi^{-}$ decay simulation with
$B^{\mp} \to \pi^{\mp}\ \chi_c$ events component

Equals magnitudes and phase differences:
delta+ = π/2   delta- = 0





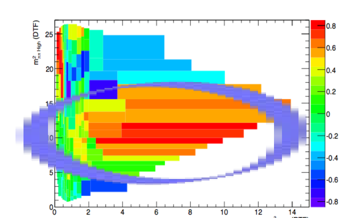
Apparent CP violation for the $B^{\mp} \to \pi^{\mp}\ \chi_c$ created by the interference term

Eilam, Gronau, Mendel.Phys.Rev.Lett. 74 (1995) 4984

In the limit of a null Penguin contribution, the phase difference between $B^{\mp} \to \rho\pi^{\mp}$ and $B^{\mp} \to \pi^{\mp}\ \chi_c$ is equal to 2γ

I. B, R. Blanco, C. Gobel, R. Mendez-Galain.Phys.Rev.Lett. 81 (1998) 4067-4070.

Behaviour of the CP distribution around the charmonioum resonance χ_c, can shown the nature of NR component (see Paticias's talk)



Summary

- *CPT constraint must be take in account in three body charmless B decay.*
- *CP violation in* $B^{\mp} \rightarrow \pi^{\mp}\pi^{+}\pi^{-}$ *and* $B^{\mp} \rightarrow \pi^{\mp}K^{+}K^{-}$, $B^{\mp} \rightarrow K^{\mp}\pi^{+}\pi^{-}$ *and* $B^{\mp} \rightarrow K^{\mp}K^{+}K$ *decays seems present together compatibility with CPT constraint.*
- *S and P wave interference has a clear signature in CP violation distributions*
- *Amplitude* $\pi^{+}\pi^{-} \rightarrow K^{+}K^{-}$ *play an important rule in these decays.*
- $B \rightarrow Rh$ *CP violation is suppressed following 2 + 1 approximation, for* $M_R < 1GeV$
- *Five times more data was are in tape*
- *Many new results are expecting soon.*