Suppressed $B \to PV$ CP asymmetry: CPT constraint

Model Independent search for direct CPV in $B \to VP$ decays

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Outline

- Motivation
- Generalities of the method
- Toy MC studies
- Conclusions

Motivation/Introduction

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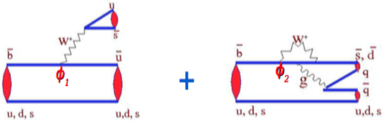
Main goal: present a novel method to measure the A_{CP} in $B \to VP$ decays.

- CPV in $B^+ \to h^- h^+ h^+$ decays is manifested through various mechanisms.
  - Large CP violation observed in LHCb.
- CPT theorem requires direct CPV to fulfill some constraints
  - As CPT implies a global conservation, direct CPV needs to be compensated between coupled channels.
- With this new method we identify the source of CPV and extract the local A_{CP} directly from data
  - No need for a time-consuming Amplitude Analysis
  - Avoid model dependence when extracting parameters of CP assymetry
- A paper explaining this method is already published in PRD [Phys.Rev.D94.054028]

- CPV from BSS
  - 2 amplitude with different weak and strong phases:



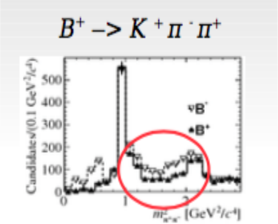
  - tree and penguin interference

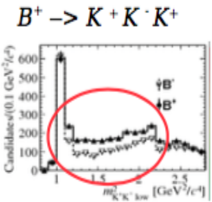
- CPV from FSI
  - $\neq$ sources of strong phase $\Longrightarrow$
    - resonances interference in $\neq$ partial waves
    - Like S-wave $\pi^+\pi^- \to K^+K^-$

All these mechanisms were investigated for LHCb data in $B \to hhh$

CPT constraints to CPV

- CPT $\Longrightarrow \Gamma_{Tot}(B^+) = \Gamma_{Tot}(B^-)$
  - normally ignored in theoretical models
  - a CP asymmetry in one channel must be compensated by an asymmetry with opposite sign in a coupled channel
  - hadronic rescattering provides a $\neq$ strong phase [Wolfenstein, PRD 43 (1991) 151]
- Ex: CP violation on channels $B^+ \to K^+\pi^+\pi^-$ and $B^+ \to K^+K^+K^-$ have opposite signal and are placed in the same region of Dalitz plot i.e. where $\pi^+\pi^- \to K^+K^-$





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Theory predictions usually involve $B \to PV$ & $B \to PP$

Direct CP assymmetries in $B \to PV$ (with QCD factorisation):

f	NLO	NNLO	NNLO + LD	Exp
$\pi^- \bar{K}^{*0}$	$1.36\,^{+0.25}_{-0.26}\,^{+0.60}_{-0.47}$	$1.49\,^{+0.27}_{-0.29}\,^{+0.69}_{-0.56}$	$0.27\,^{+0.05}_{-0.05}\,^{+3.18}_{-0.67}$	-3.8 ± 4.2
$\pi^0 K^{*-}$	$13.85\,^{+2.40}_{-2.70}\,^{+5.84}_{-5.86}$	$18.16\,^{+3.11}_{-3.52}\,^{+7.79}_{-10.57}$	$-15.81\,^{+3.01}_{-2.83}\,^{+69.35}_{-15.39}$	-6 ± 24
$\pi^+ K^{*-}$	$11.18\,^{+2.00}_{-2.15}\,^{+9.75}_{-10.62}$	$19.70\,^{+3.37}_{-3.80}\,^{+10.54}_{-11.42}$	$-23.07\,^{+4.35}_{-4.05}\,^{+86.20}_{-20.64}$	-23 ± 6
$\pi^0 \bar{K}^{*0}$	$-17.23\,^{+3.33}_{-3.00}\,^{+7.59}_{-12.57}$	$-15.11\,^{+2.93}_{-2.65}\,^{+12.34}_{-10.64}$	$2.16\,^{+0.39}_{-0.42}\,^{+17.53}_{-36.80}$	-15 ± 13
$\delta(\pi \bar{K}^*)$	$2.68\,^{+0.72}_{-0.67}\,^{+5.44}_{-4.30}$	$-1.54\,^{+0.45}_{-0.58}\,^{+4.60}_{-9.19}$	$7.26\,^{+1.21}_{-1.34}\,^{+12.78}_{-20.65}$	17 ± 25
$\Delta(\pi \bar{K}^*)$	$-7.18\,^{+1.38}_{-1.28}\,^{+3.38}_{-5.35}$	$-3.45\,^{+0.67}_{-0.59}\,^{+9.48}_{-4.95}$	$-1.02\,^{+0.19}_{-0.18}\,^{+4.32}_{-7.86}$	-5 ± 45
$\rho^- \bar{K}^0$	$0.38\,^{+0.07}_{-0.07}\,^{+0.16}_{-0.27}$	$0.22\,^{+0.04}_{-0.04}\,^{+0.19}_{-0.17}$	$0.30\,^{+0.06}_{-0.06}\,^{+2.28}_{-2.39}$	-12 ± 17
$\rho^0 K^-$	$-19.31\,^{+3.42}_{-3.61}\,^{+13.95}_{-8.96}$	$-4.17\,^{+0.75}_{-0.80}\,^{+19.26}_{-19.52}$	$43.73\,^{+7.07}_{-7.62}\,^{+44.00}_{-137.77}$	37 ± 11
$\rho^+ K^-$	$-5.13\,^{+0.95}_{-0.97}\,^{+6.38}_{-4.02}$	$1.50\,^{+0.29}_{-0.27}\,^{+8.69}_{-10.36}$	$25.93\,^{+4.43}_{-4.90}\,^{+25.40}_{-75.63}$	20 ± 11
$\rho^0 \bar{K}^0$	$8.63\,^{+1.59}_{-1.65}\,^{+2.31}_{-1.69}$	$8.99\,^{+1.66}_{-1.71}\,^{+3.60}_{-7.44}$	$-0.42\,^{+0.08}_{-0.08}\,^{+19.49}_{-8.78}$	6 ± 20
$\delta(\rho \bar{K})$	$-14.17\,^{+2.80}_{-2.96}\,^{+7.98}_{-5.39}$	$-5.67\,^{+0.96}_{-1.01}\,^{+10.86}_{-9.79}$	$17.80\,^{+3.15}_{-3.01}\,^{+19.51}_{-62.44}$	17 ± 16
$\Delta(\rho \bar{K})$	$-8.75\,^{+1.62}_{-1.66}\,^{+4.78}_{-6.48}$	$-10.84\,^{+1.98}_{-2.09}\,^{+11.67}_{-9.09}$	$-2.43\,^{+0.46}_{-0.42}\,^{+4.60}_{-19.43}$	-37 ± 37

M. Beneke (TU Munchen), QCDF phenomenology, Bad Honnef 2016

- In $(2+1)$ approx: There is no CPV in $B \to PV$
  - $K^*(892)$ and $\rho(770)$ decay $\sim$100% to $K\pi$ and $\pi\pi$
  - $\phi(1020)$ is different (15% to $\pi\rho$) but exclusively penguin (do not produce CPV)
- The CP asymmetry, if present, comes from resonances interference in different partial waves
- What about data?
  - different resonances interfere in the same region of Dalitz plot
  - Isobar Model $\Longrightarrow$ values of A_{CP} are model dependent

Want to track directly from data the type of CP violation in $B \to PV$ decays around the resonances

Starting with a vector and a NR amplitude

$$\mathcal{M}_+ = a_+^V e^{i\delta_+^V} F_V^{BW} \cos\theta(s_\perp, s_\parallel) + a_+^{nr} e^{i\delta_+^{nr}} F^{NR}$$
$$\mathcal{M}_- = a_-^V e^{i\delta_-^V} F_V^{BW} \cos\theta(s_\perp, s_\parallel) + a_-^{nr} e^{i\delta_-^{nr}} F^{NR}$$

$s_\parallel =$ resonance channel, $s_\perp =$ perpendicular channel

- the values of $cos(\theta)$ remain stable as a function of $s_\perp$ around the center value of $s_\parallel = m_V^2$
- the helicity angle can be assumed to be a function of only $s_\perp$

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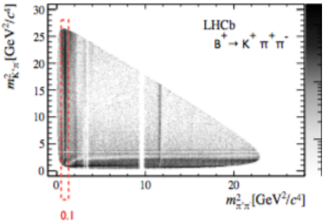
model independent method

- we select a small region around the resonance in s∥ and look for the distribution $\Delta|\mathcal{M}^2|$ on s⊥
  - $s_\parallel \approx m_V^2$ → cosθ (s⊥)



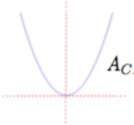
$$\Delta|\mathcal{M}^2| = |\mathcal{M}_+|^2 - |\mathcal{M}_-|^2$$

$$= [(a_+^V)^2 - (a_-^V)^2]|F_V^{BW}|^2 \cos^2\theta(s_\perp, s_\parallel) + [(a_+^{nr})^2 - (a_-^{nr})^2]|F^{NR}|^2 \; + 2\cos\theta(s_\perp, s_\parallel)|F_V^{BW}|^2|F^{NR}|^2 \times$$

$$\{(m_V^2 - s_\parallel))\;[a_+^V a_+^{nr}(\cos(\delta_+^V - \delta_+^{nr}) - a_-^V a_-^{nr}\cos(\delta_-^V - \delta_-^{nr})] \; - m_V\Gamma_V \; [a_+^V a_+^{nr}(\sin(\delta_+^V - \delta_+^{nr}) - a_-^V a_-^{nr} \sin(\delta_-^V - \delta_-^{nr})]\}.$$

- parametrize $\Delta|\mathcal{M}|^2 = a(x - c_0)^2 + b(x - c_0) + c$ for $\cos\theta = x - c_0$

$\boxed{a \Rightarrow \text{BSS \& Acp}}$



$$A_{CP} = \frac{a^+ - a^-}{a^+ + a^-}$$

$\boxed{b \Rightarrow \text{interference}}$

$\boxed{c \Rightarrow \text{NR BSS}}$

constant

For a vector resonance in a $B^+ \to h^- h^+ h^+$ decay defined by the Dalitz invariants (S_{ij}, S_{ik}):

- Get a slice of mass in S_{ij} ($\parallel$ to the resonance)
- Integrate the distribution of S_{ik} ($\perp$ to the resonance) for B^+ and B^-
- Fit these distributions with 2^{nd} order functions
- Obtain the A_{CP} using the main coefficients from the fitted functions
- Fit equation: $a(x - x_0)^2 + b(x - x_0) + c$
- $A_{CP_{res}}(\%) = \left(\frac{a^- - a^+}{a^- + a^+}\right) * 100$

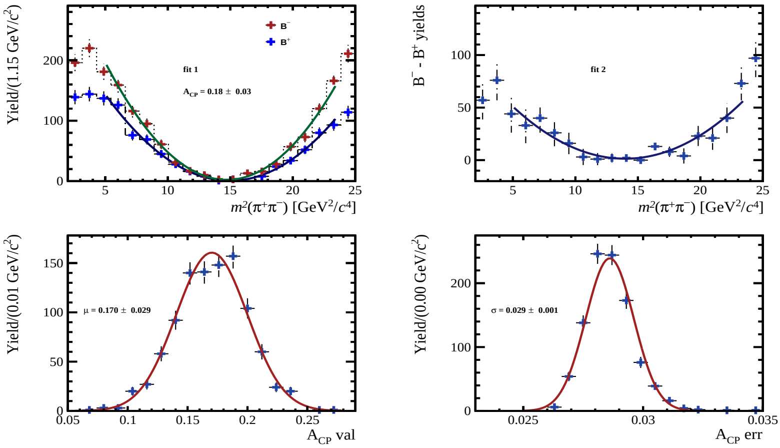
Toy MC studies

Toy MC studies

Values from BaBar Model [PhysRevD.79.072006(2009)].

Mode	x	y	Δ_x	Δ_y	Fraction(%)	A_{CP}(%)
$\rho(770)\pi^+$	1.0 [fixed]	0.0 [fixed]	-0.092 ± 0.036	0.0 [fixed]	53.2 ± 3.7	$+18 \pm 7$
$\rho(1450)\pi^+$	-0.292 ± 0.071	0.175 ± 0.078	0.109 ± 0.080	0.211 ± 0.073	9.1 ± 2.3	$-\ 6 \pm 28$
$f_2(1270)\pi^+$	0.136 ± 0.064	0.149 ± 0.052	0.101 ± 0.063	-0.248 ± 0.052	5.9 ± 1.6	$+41 \pm 25$
$f_0(1370)\pi^+$	0.397 ± 0.067	-0.151 ± 0.081	-0.387 ± 0.064	-0.168 ± 0.086	18.9 ± 3.3	$+72 \pm 15$
NR	-0.200 ± 0.091	-0.682 ± 0.070	-0.392 ± 0.089	0.046 ± 0.069	34.9 ± 4.2	-14 ± 14

- Using Laura$++$ Toy MC Generator.
- We generated 1000 samples each with 20 000 events.
- Choose a 150 MeV window around $\rho(770)$ mass.
- Fitted B^+ and B^- in each sample with quadratic polynomial equation (fit 1).
- Calculate $\rho(770)$'s A_{CP} using the main coefficient obtained from fit in each equation.
- Fit equation: $a(x-p_1)^2 + b(x-p_1) + c$, with $p_1 = 13.76$
- $A_{CP_{res}} = \frac{a^- - a^+}{a^- + a^+}$
- We also fit the $B^- - B^+$ binned differences (fit 2).
- A straight line must be obtained from fit 2 (if no A_{CP} was found in fit 1)
- Fit 2 must yield a parable when A_{CP} is present



Top: Fit to B^+ and B^- distribution in a random sample generated with $A_{CP} = 0.18$ in $\rho(770)$. Bottom: Distribution of the A_{CP} and its error.

Toy MC studies

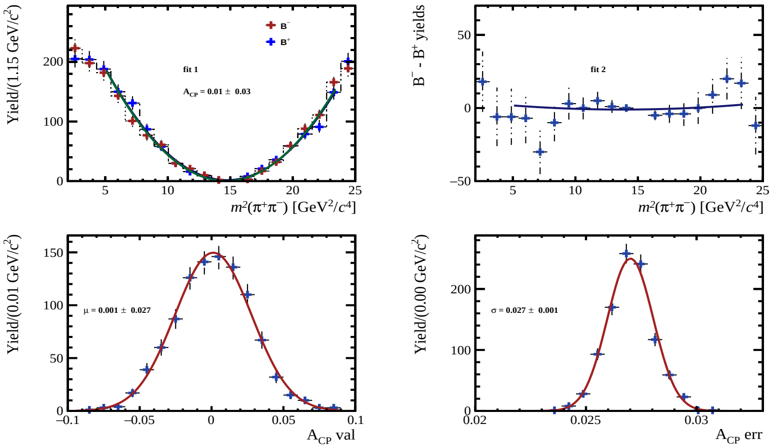
Values from BaBar Model [PhysRevD.79.072006(2009)].

Mode	x	y	Δ_x	Δ_y	Fraction(%)	A_{CP}(%)
$\rho(770)\pi^+$	1.0 [fixed]	0.0 [fixed]	0.0	0.0 [fixed]	53.2 ± 3.7	0.0
$\rho(1450)\pi^+$	-0.292 ± 0.071	0.175 ± 0.078	0.109 ± 0.080	0.211 ± 0.073	9.1 ± 2.3	$-\ 6 \pm 28$
$f_2(1270)\pi^+$	0.136 ± 0.064	0.149 ± 0.052	0.101 ± 0.063	-0.248 ± 0.052	5.9 ± 1.6	$+41 \pm 25$
$f_0(1370)\pi^+$	0.397 ± 0.067	-0.151 ± 0.081	-0.387 ± 0.064	-0.168 ± 0.086	18.9 ± 3.3	$+72 \pm 15$
NR	-0.200 ± 0.091	-0.682 ± 0.070	-0.392 ± 0.089	0.046 ± 0.069	34.9 ± 4.2	-14 ± 14

- Model without A_{CP} in $\rho(770)$
- We generated 1000 samples each with 20 000 events.
- Fitted B^+ and B^- in each sample with quadratic polynomial equation (fit 1).
- Calculate $\rho(770)$'s A_{CP} using the main coefficient obtained from fit in each equation.

- Fit equation: $a(x - p_1)^2 + b(x - p_1) + c$, with $p_1 = 13.76$
- $A_{CP_{res}} = \frac{a^- - a^+}{a^- + a^+}$
- We also fit the $B^- - B^+$ binned differences (fit 2).
- A straight line must be obtained from fit 2 (if no A_{CP} was found in fit 1)
- Fit 2 must yield a parable when A_{CP} is present

Toy MC studies (1K samples, 20K evts, $B \to \rho(770)\pi$, $A_{CP} = 0.0$)



Top: Fit to B^+ and B^- distribution in a random sample generated with $A_{CP} = 0.0$ in $\rho(770)$. Bottom: Distribution of the A_{CP} and its error.

From Toy MC simulations:

- The chosen region in all fits corresponds to the PDG width arround the ressonance.
- Variations in mass window ($\parallel$) do not affect the central value of A_{CP} (only its error).
- Excluded regions in $\perp$ mass window do not change the result.
  - The excluded regions are those with vetos, low statistics, etc.

Conclusions

- We propose a new method to perform the Model Independent search for direct CPV in $B \to VP$ decays
- $A_{CP} = \frac{a^+ - a^-}{a^+ + a^-} \Longrightarrow$ an indication of a CPV from BSS mechanism
- Toy MC studies show this is a reliable method.
- We can limit the fit region to avoid the influence of crossed channels
- It works better when the scalar is far from vector and have small magnitude ($B^\pm \to K^\pm \pi^+ \pi^-$)
- Paper published in PRD
- We are already applying this method on LHCb data.

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