DIRECT CP VIOLATION IN CHARMLESS B DECAYS AT LHCb

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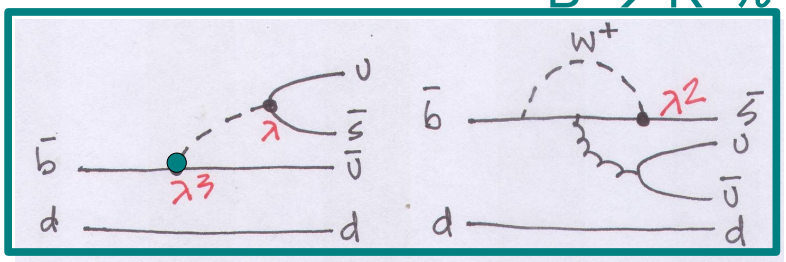
For LHCb collaboration

CKM2012
Cincinnati, 28/SET-2/OCT

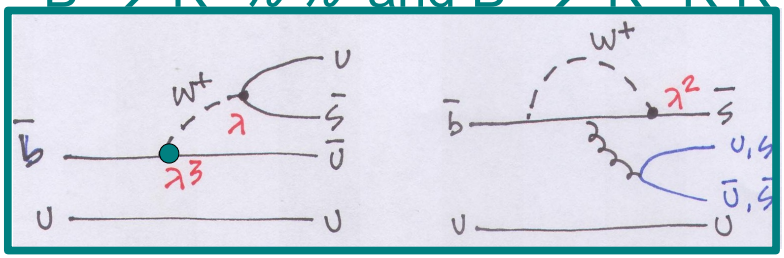
outline

- overview
- first evidence of direct $\not{CP}$ in $B_s^0 \rightarrow K^- \pi^+$ and precision at $B^0 \rightarrow K^+ \pi^-$
  PRL **108**,201601(2012) L= 0.35 fb^{-1}
- evidence of direct $\not{CP}$ in $B^\pm \rightarrow K^\pm \pi^+\pi^-$ and $B^\pm \rightarrow K^\pm K^+K^-$
  LHCb-CONF-2012-018 preliminary L= 1.0 fb^{-1}
- evidence of direct $\not{CP}$ in $B^\pm \rightarrow \pi^\pm K^+K^-$ and $B^\pm \rightarrow \pi^\pm\pi^+\pi^-$
  LHCb-CONF-2012-028 preliminary L= 1.0 fb^{-1} **new**
- conclusion

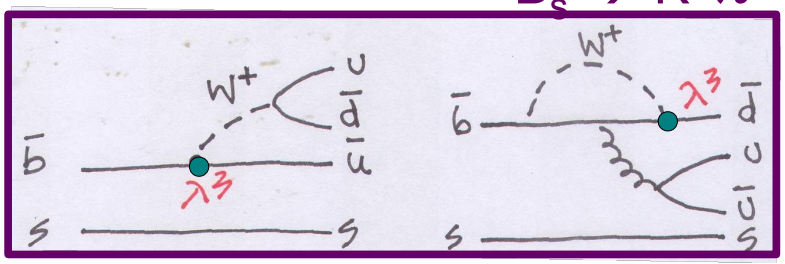
$B^0 \rightarrow K^+ \pi^-$



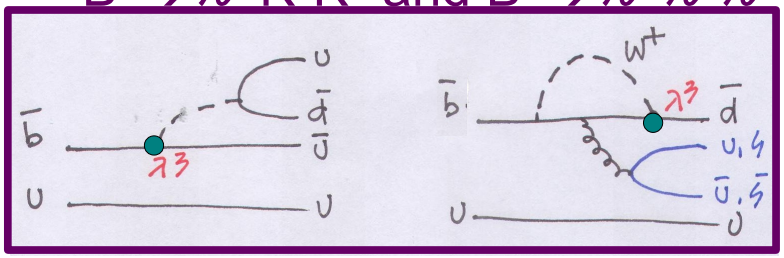
$B^{\pm} \rightarrow K^{\pm} \pi^+\pi^-$ and $B^{\pm} \rightarrow K^{\pm} K^+K^-$



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

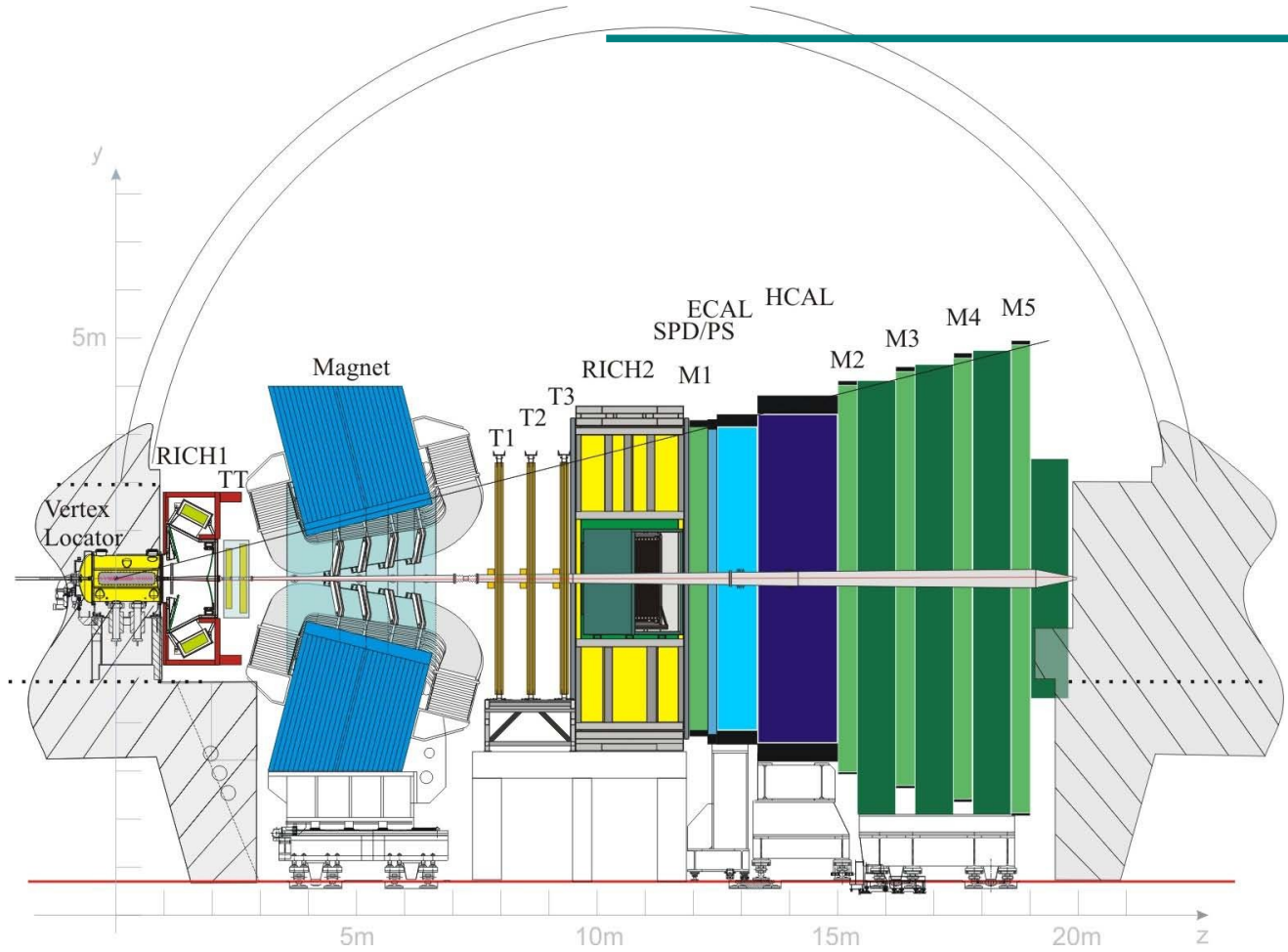


$B^{\pm} \rightarrow \pi^{\pm} K^+K^-$ and $B^{\pm} \rightarrow \pi^{\pm} \pi^+\pi^-$



- access to CKM ~~CP~~ transitions b→u and t→d •• γ at tree level •• probe to new physics.
- similar diagrams for two and three body •• mainly tree and penguin contributions.
- penguin amplitudes expected to be small •• extra suppression in $\propto\lambda^3$ modes.
- rich Dalitz plot interference pattern for three body modes.
- extensively studied by b factories and tevatron yet new intriguing results.
- observable:

$$A_{CP} = \frac{\Gamma(B^- \rightarrow f) - \Gamma(B^+ \rightarrow \bar{f})}{\Gamma(B^- \rightarrow f) + \Gamma(B^+ \rightarrow \bar{f})}$$



- 2011 luminosity 1.0fb^{-1}
- excellent tracking and vertexing
- excellent particle identification
- magnet, reversion of polarity
- efficient hadronic triggers (particularly for B→ hh)

L= 0.35 fb^{-1} $B_s^0 \to K^- \pi^+$ and $B^0 \to K^+ \pi^-$

PRL **108**,201601(2012)

- $A_{CP}(B^0 \to K\pi) = \dfrac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$ **PDG = -0.097± 0.012**

- $A_{CP}(B_s^0 \to \pi K) = \dfrac{\Gamma(\bar{B}_s^0 \to \pi^-K^+) - \Gamma(B_s^0 \to \pi^+K^-)}{\Gamma(\bar{B}_s^0 \to \pi^-K^+) + \Gamma(B_s^0 \to \pi^+K^-)}$ **= 0.39 ±0.17***

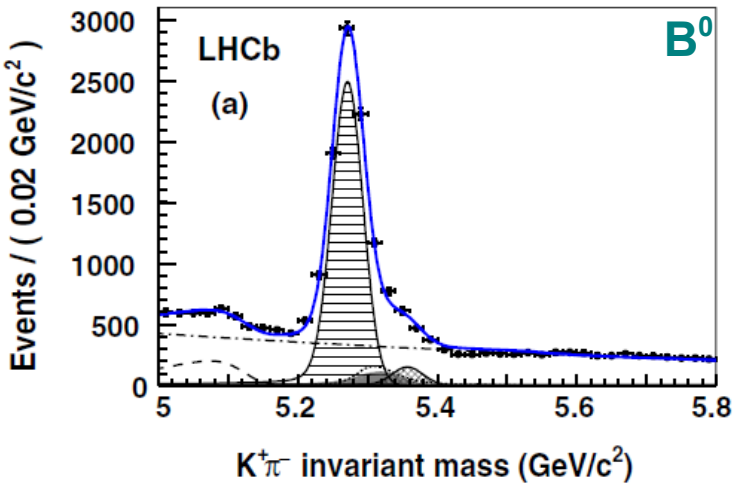
* CDF(PRL**106**(2011)181802)

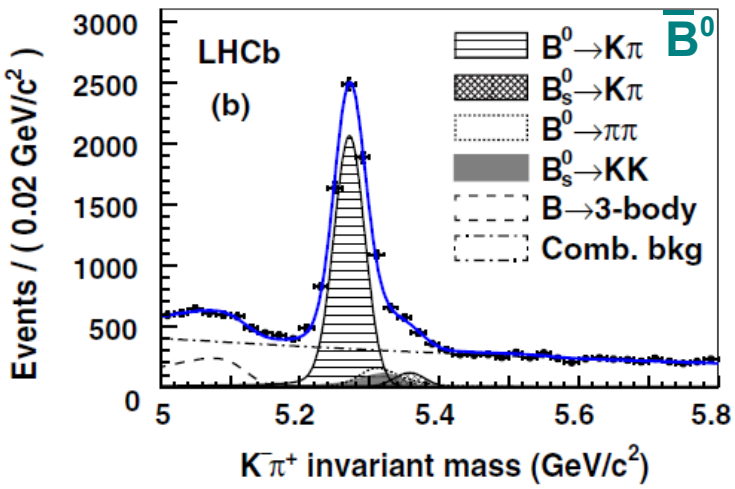
- no prior evidence of ~~CP~~ in B_s^0 system •• simplest hadronic measurement

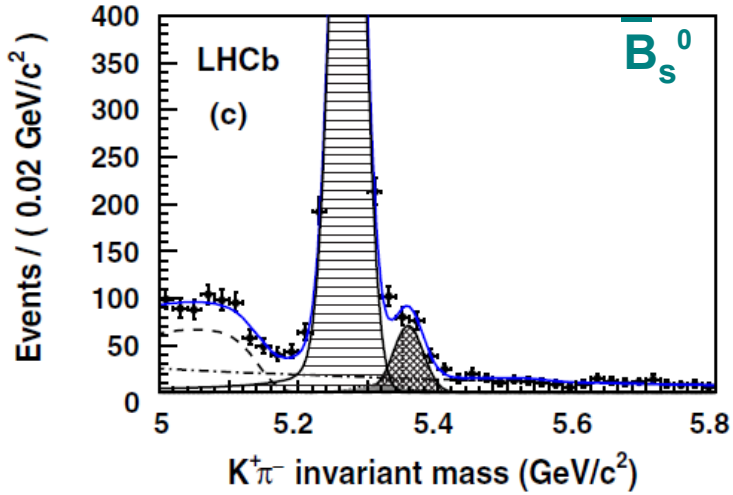
- **ANALYSIS**:
  - very efficient hadronic trigger •• one high P_t track
  - $B_s^0 \to K\pi$ ~14×lower decay rate and ~4 × lower production than $B^0 \to K\pi$
    ➡ tighter selection for B_s^0
  - magnetic field polarity reversion •• minimizes instrumental charge asymmetry
    ➡ L= 0.35fb^{-1} = 0.15fb^{-1}(up) 0.20fb^{-1} (down)
  - inclusive hh selection under $\pi^+\pi^-$ mass hypothesis within 4.7-5.9 GeV/c²
    ➡ RICH particle ID to distinguish modes and estimate cross-feed background
    •• relative efficiencies from D^{*+} and Λ calibration samples

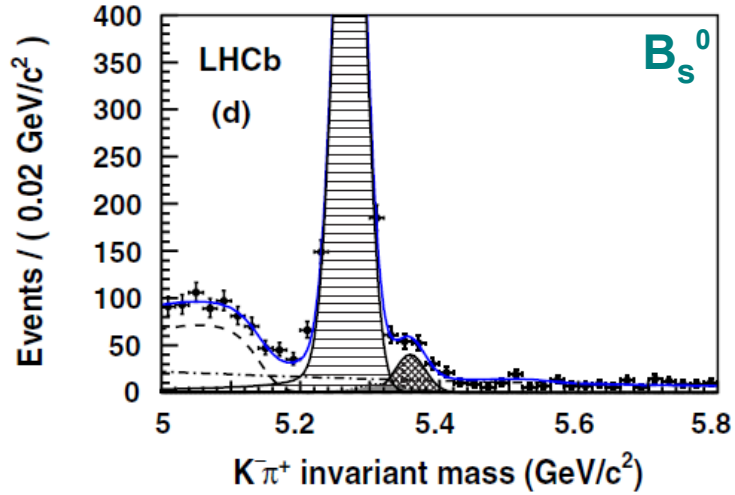
$B_s^0 \to K^- \pi^+$ and $B^0 \to K^+ \pi^-$

PRL **108**,201601(2012)









- unbinned maximum likelihood fit:
  - $N(B^0 \to K\pi) = 13\,250 \pm 150$
  - $N(B_s^0 \to K\pi) = 314 \pm 27$

$$A_{\rm raw}(B^0 \to K\pi) = -0.095 \pm 0.011$$
$$A_{\rm raw}(B_s^0 \to K\pi) = 0.28 \pm 0.08$$

$$A_{CP} = A_{\rm raw} \pm A_D(K\pi) - \kappa_{d(s)} A_P(B^0_{(s)})$$

corrections:

- **instrumental** from D* and untagged D→ hh ⇒ $A_D = -0.010 \pm 0.02$
- $B^0_{(s)}$ -$\bar{B}^0_{(s)}$ **mixing** ⇒ $\kappa_d = 0.303 \pm 0.005$, $\kappa_s = -0.033 \pm 0.003$
- **production** from $B^0 \to J/\psi K^{*0}$ ⇒ $A_P(B^0) = 0.010 \pm 0.013$

total corrections

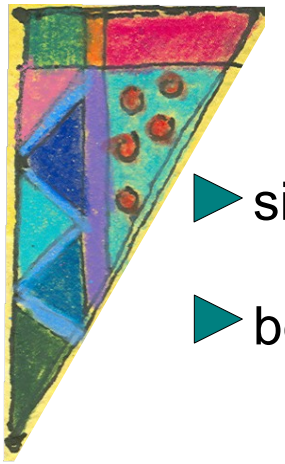
$$A_\Delta(B^0 \to K\pi) = -0.007 \pm 0.006$$
$$A_\Delta(B^0_s \to K\pi) = 0.010 \pm 0.002$$

$$A_{CP}(B^0 \to K\pi) = -0.088 \pm 0.011(\text{stat}) \pm 0.008(\text{syst})$$

most precise >6σ

$$A_{CP}(B^0_s \to K\pi) = 0.27 \pm 0.08(\text{stat}) \pm 0.02(\text{syst}).$$

first evidence 3.3σ



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

preliminary LHCb-CONF-2012-018

$L = 1.0\ fb^{-1}$

- similar physics •• γ in tree $\propto\lambda^4$ •• penguin $\propto\lambda^2$
- belong to the same strong interaction "family":

from CPT (bigi&sanda 2nd edition pp 57)

$$\sum_{f_\alpha^{(i)} \in F_i} \Gamma\left(P \to f_\alpha^{(i)}\right) = \sum_{\bar{f}_\alpha^{(i)} \in \bar{F}_i} \Gamma\left(\bar{P} \to \bar{f}_\alpha^{(i)}\right)$$

in F_i all f_α connected via strong interactions

•• final states related through well stablished scattering $KK \to \pi\pi$ (PRL**45**(1980)1469)

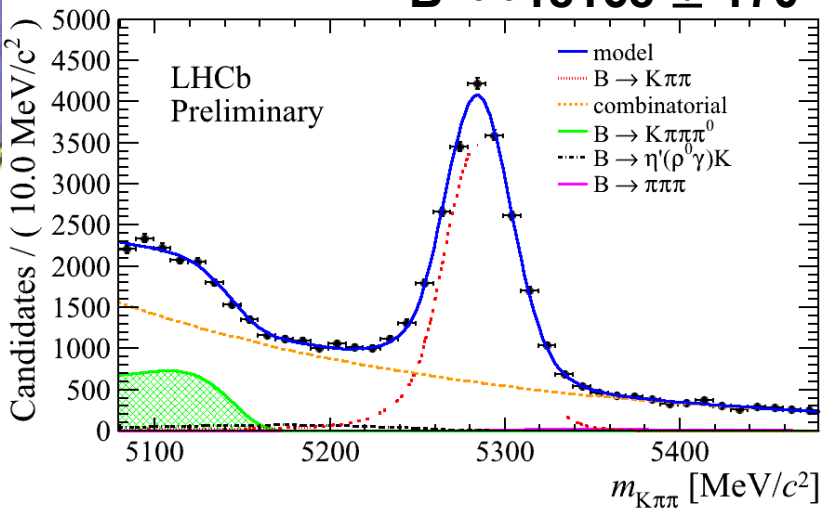
- similar statistics
- same selection except for particle ID and background vetoes
- similar experimental challenges •• use of $B \to J/\psi(\mu\mu)K$ as control channel to estimate K instrumental and B production asymmetries •• ~ 60 K events
- trigger on signal and independent of signal samples

$$A_{CP}(K^{\pm}h^{+}h^{-}) = A_{CP}^{\mathrm{RAW}}(K^{\pm}h^{+}h^{-}) - A_{CP}^{\mathrm{RAW}}(J/\psi\, K^{\pm}) + A_{CP}(J/\psi\, K^{\pm})$$

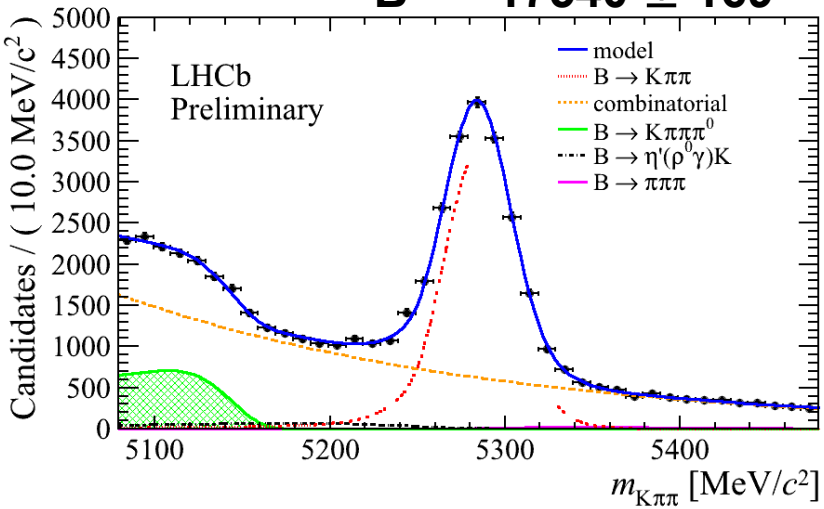
$B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \to K^{\pm}K^{+}K^{-}$

preliminary LHCb-CONF-2012-018

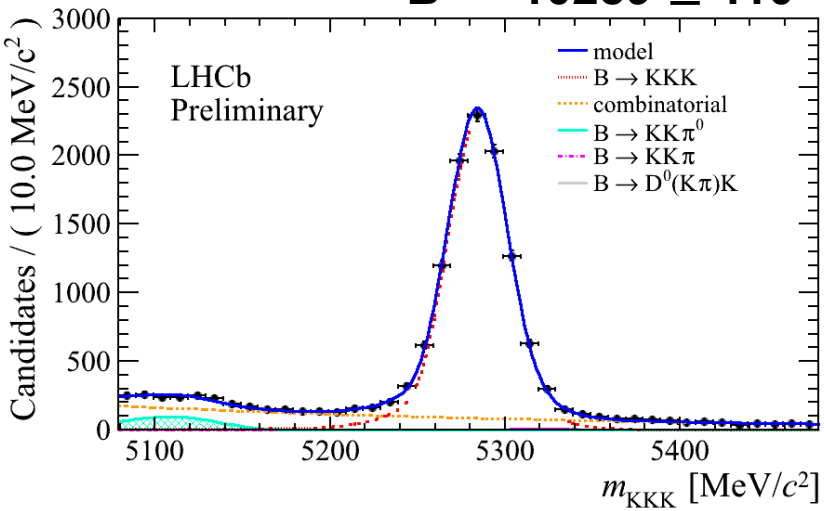
B^- 18168 ± 170



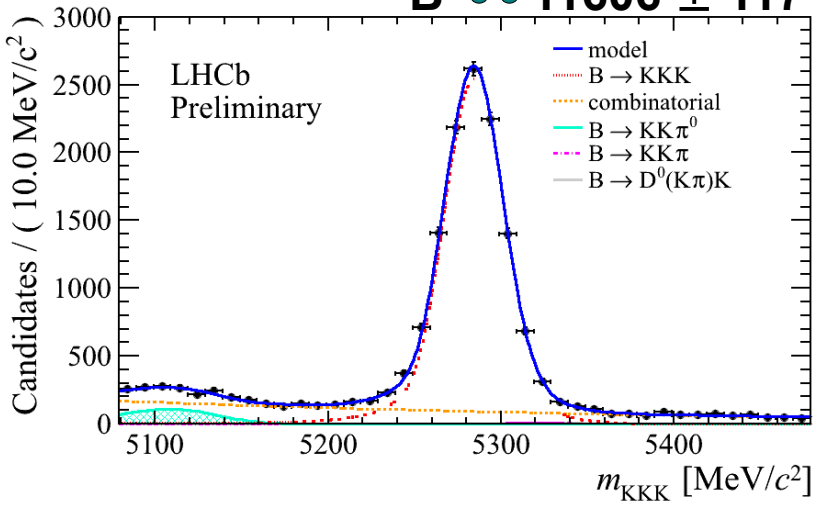
B^+ 17540 ± 169



B^- 10289 ± 110



B^+ 11606 ± 117



$$A_{CP}(B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = +0.034 \pm 0.009(\text{stat}) \pm 0.004(\text{syst}) \pm 0.007(J/\psi K^{\pm}),$$
$$A_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.046 \pm 0.009(\text{stat}) \pm 0.005(\text{syst}) \pm 0.007(J/\psi K^{\pm})$$

PDG

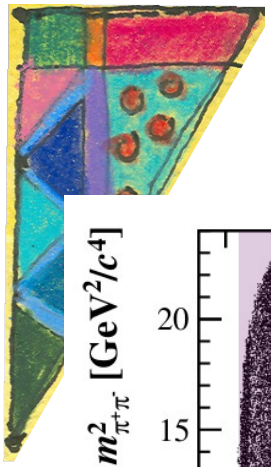
= 0.038± 0.022

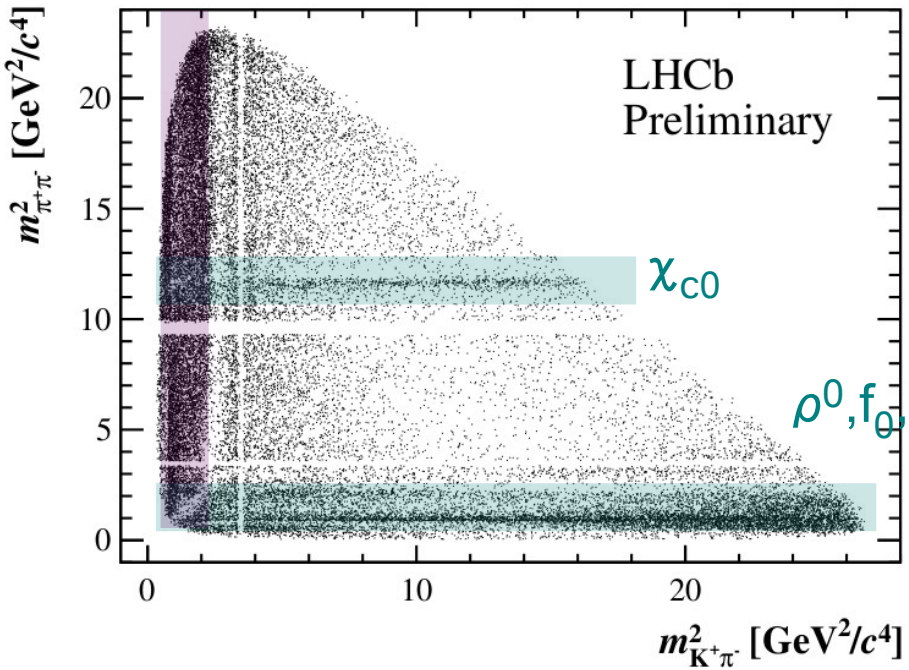
= -0.017 ± 0.030

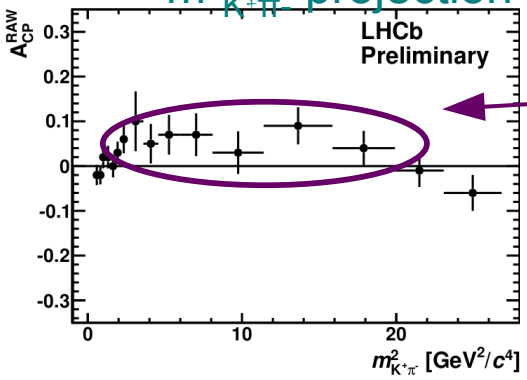
$B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ dalitz*

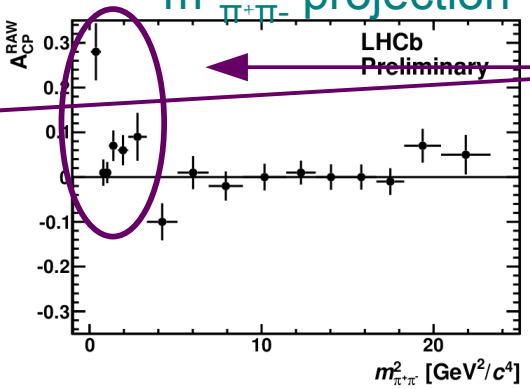
preliminary LHCb-CONF-2012-018

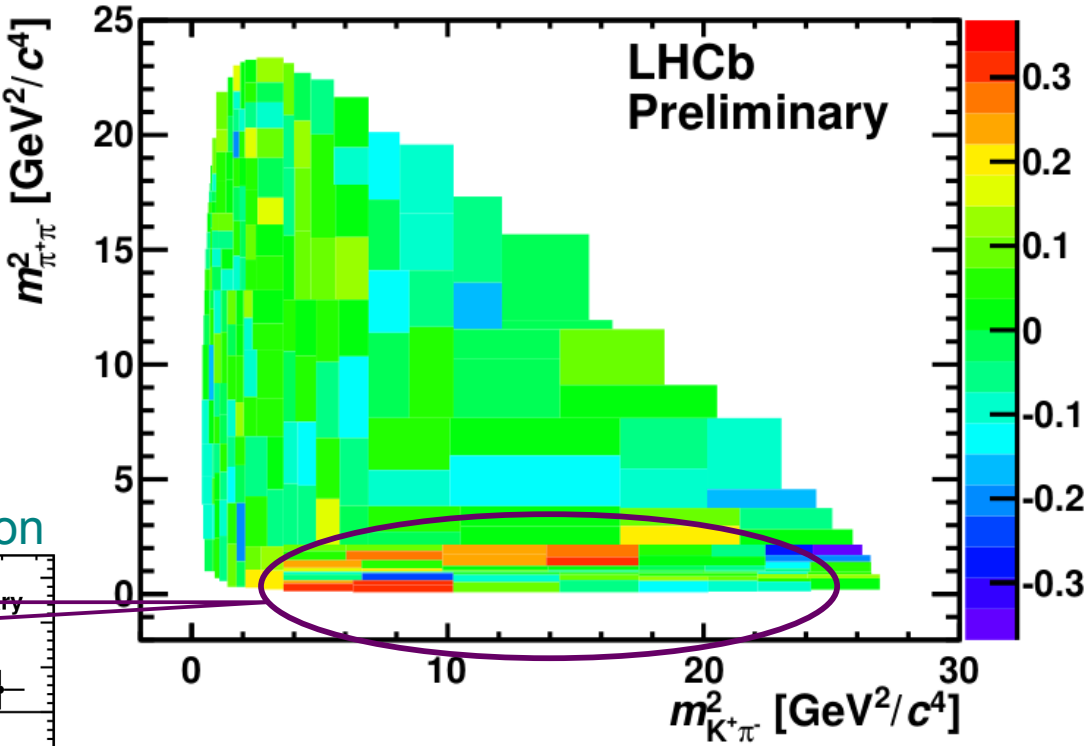
- asymmetry in the number of events:
  $A \equiv (N^{-}-N^{+})/(N^{-}+N^{+})$; N=sig+bkg
- equal population binning











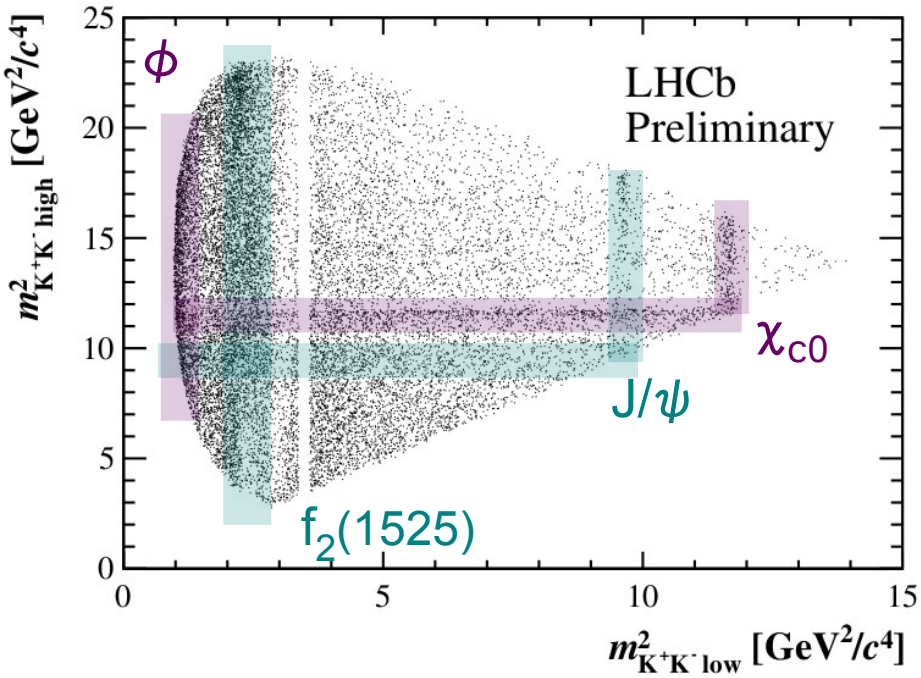
*±40MeV m_B mass window

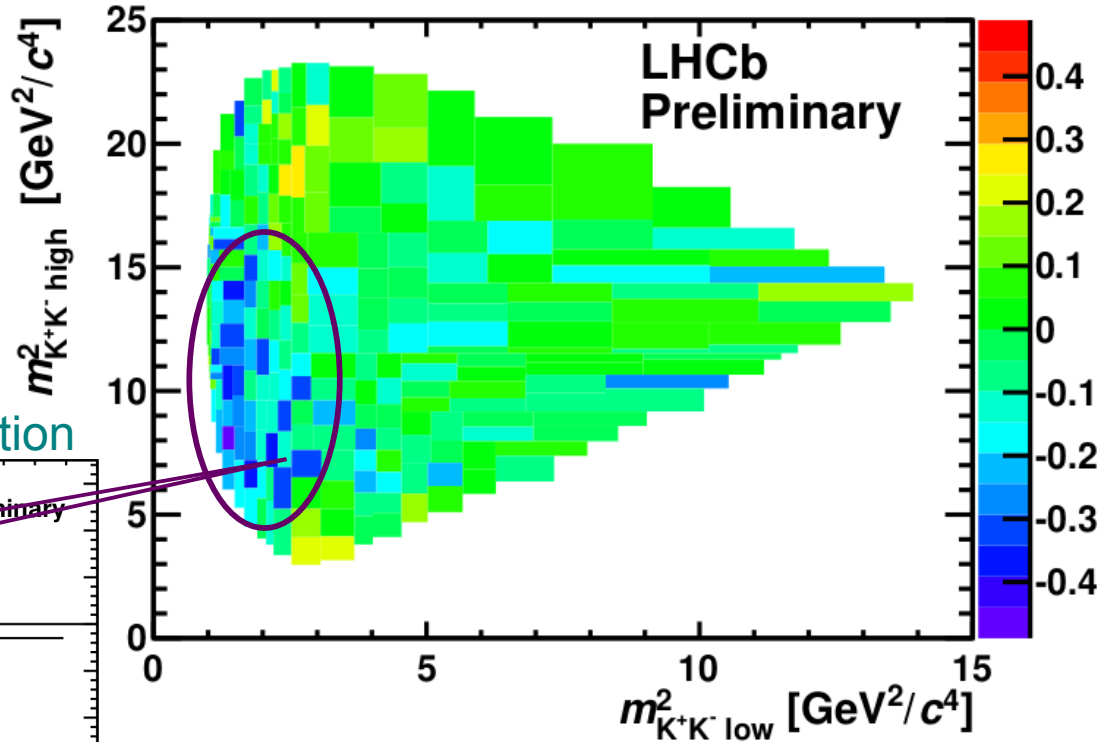
large positive CP at low $m_{\pi+\pi-}$
no evidence of CP in Kπ

$B^{\pm} \rightarrow K^{\pm}K^{+}K^{-}$ dalitz*

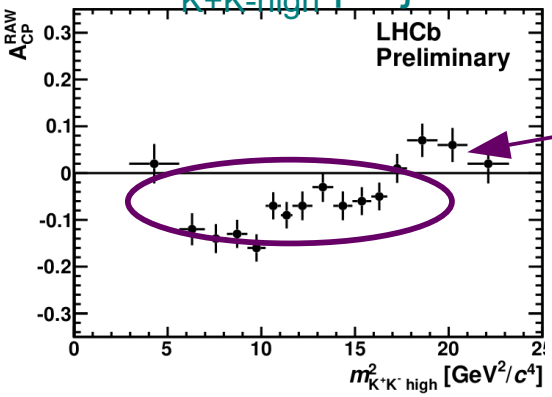
preliminary LHCb-CONF-2012-018

- asymmetry in the number of events:
  $A \equiv (N^{-}-N^{+})/(N^{-}+N^{+})$; N=sig+bkg
- equal population binning

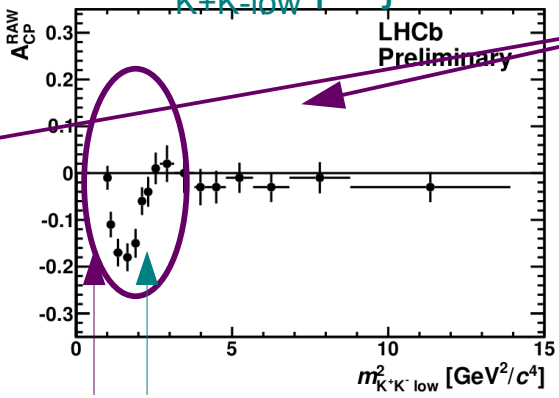




$m^2_{K+K-high}$ projection



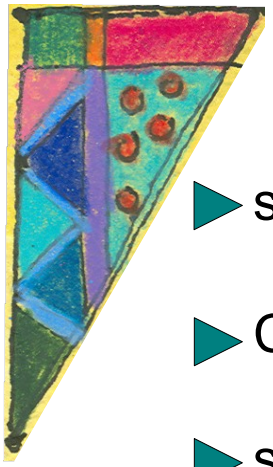
$m^2_{K+K-low}$ projection



ϕ $f_2(1525)$

very large negative ~~CP~~ at low m_{K+K-} not clearly associated to a resonance

*$\pm$40MeV m_B mass window



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

preliminary LHCb-CONF-2012-028

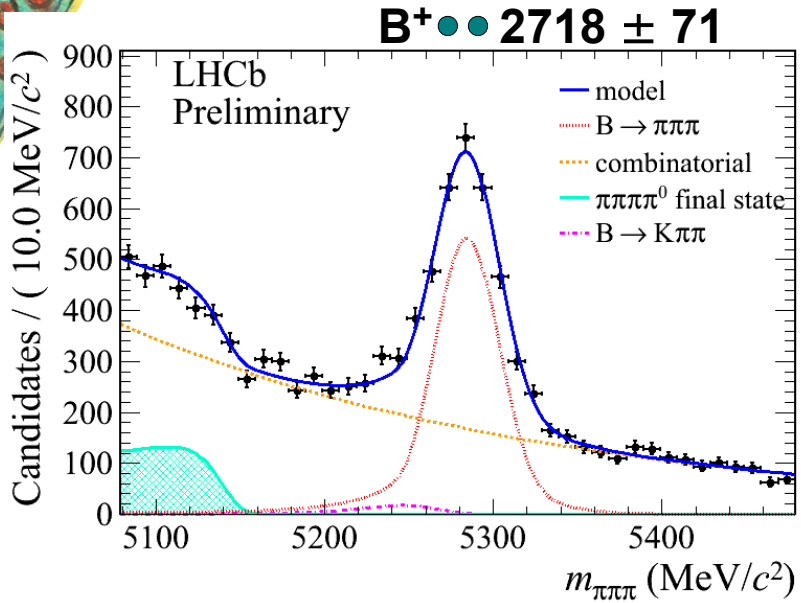
$L = 1.0\ fb^{-1}$

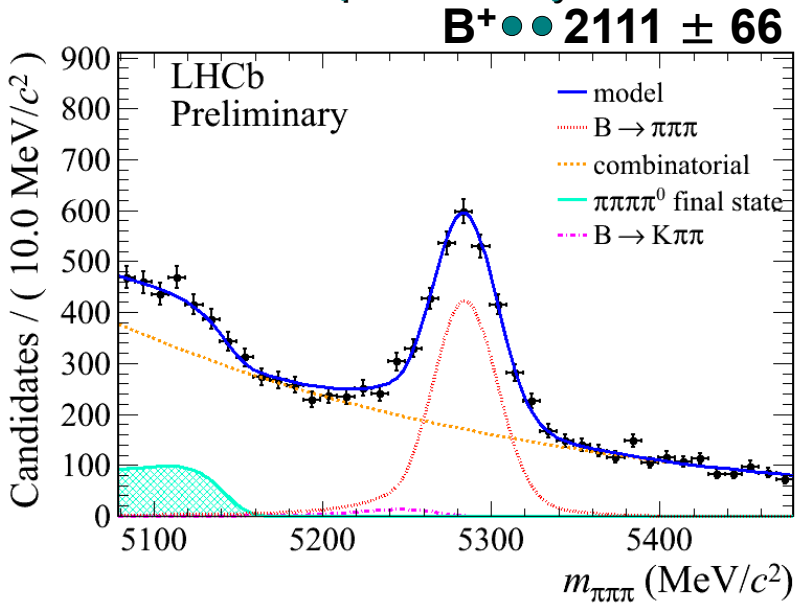
- similar physics •• γ in tree $\propto\lambda^3$ •• penguin V_{td} $\propto\lambda^3$
- CPT connected•• related final state through scattering KK→ππ.
- similar statistics •• large backgrounds
- same selection except for particle ID and background vetoes
- similar experimental challenges •• use of J/ψK as control channel to estimate production asymmetries
- trigger on signal and independent of signal sub samples
- dalitz acceptance correction

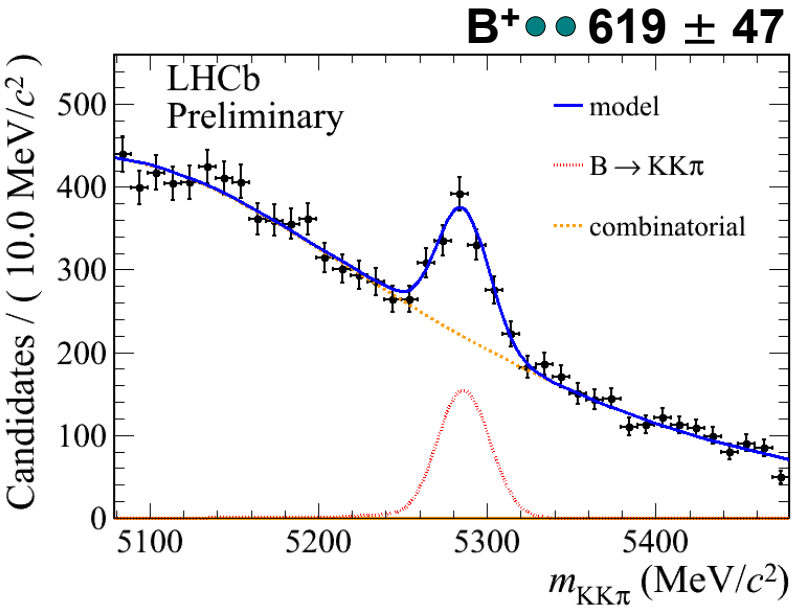
$$A_{CP}(hh\pi) = {}^{\mathrm{ACC}}A_{CP}^{\mathrm{RAW}}(hh\pi) - A_{\mathrm{P}} - A_{\mathrm{D}}^{\pi}$$

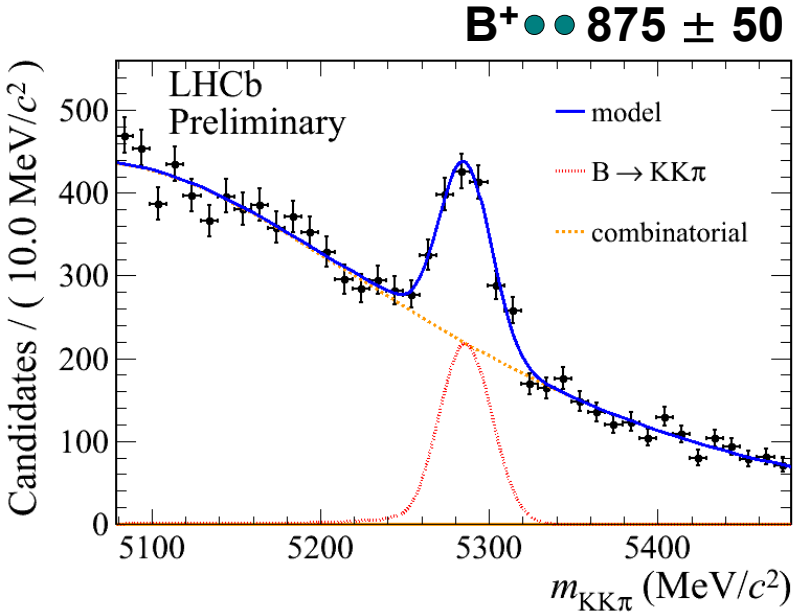
$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \to \pi^{\pm}K^{+}K^{-}$

preliminary LHCb-CONF-2012-028







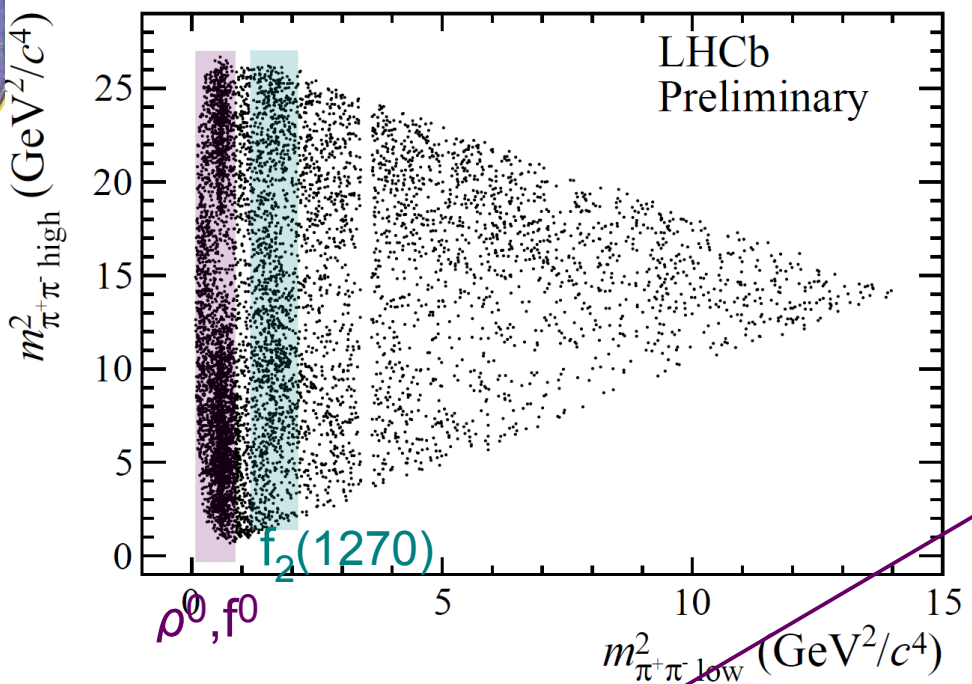


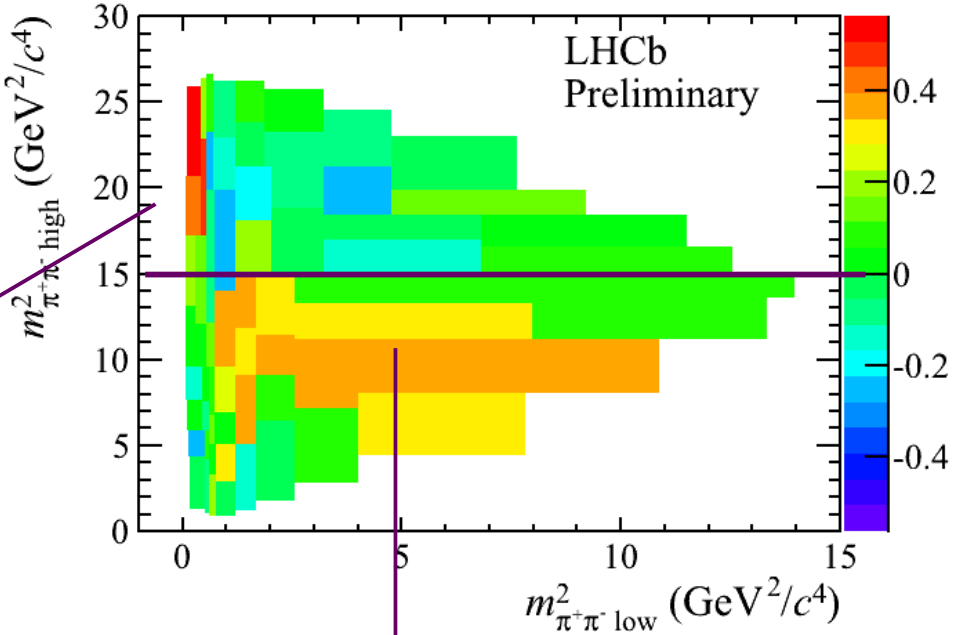
$$A_{CP}(B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}) = +0.120 \pm 0.020(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K^{\pm})$$
$$A_{CP}(B^{\pm} \to K^{+}K^{-}\pi^{\pm}) = -0.153 \pm 0.046(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K^{\pm})$$

$B^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ dalitz*

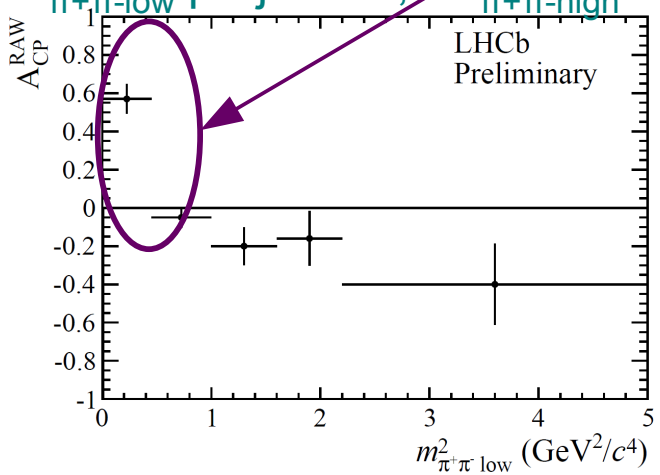
preliminary LHCb-CONF-2012-028

- asymmetry in the number of events:
  $A \equiv (N^{-}-N^{+})/(N^{-}+N^{+})$; N=sig+bkg
- equal population binning

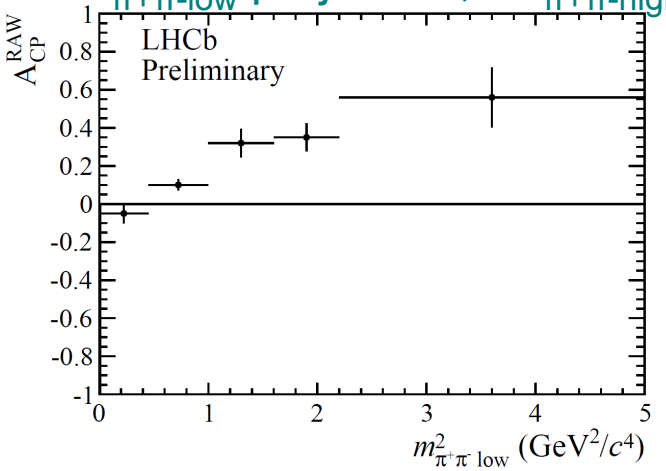




$m^2_{\pi+\pi-\text{low}}$ projection, $m^2_{\pi+\pi-\text{high}}$ >15



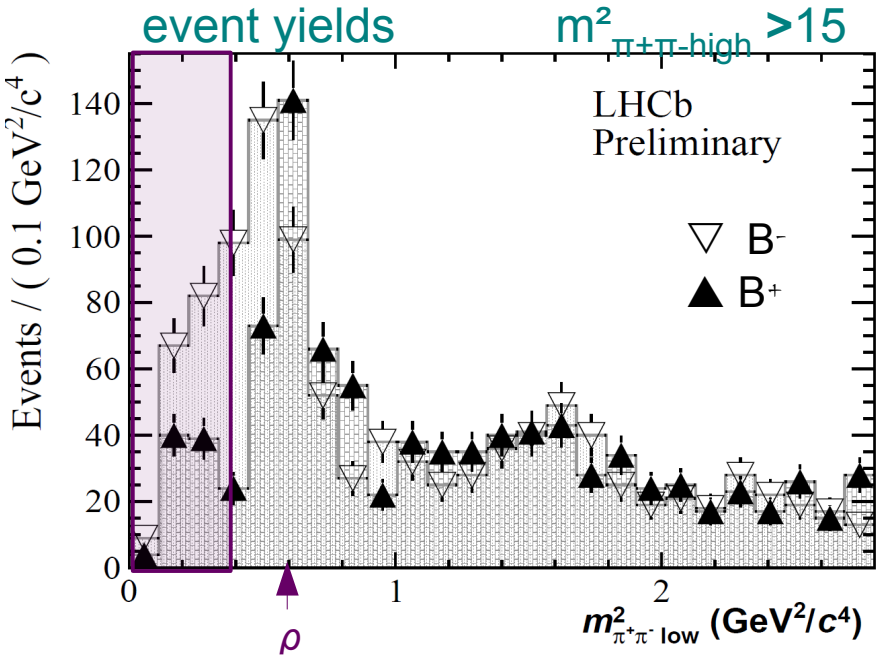
$m^2_{\pi+\pi-\text{low}}$ projection, $m^2_{\pi+\pi-\text{high}}$ <15



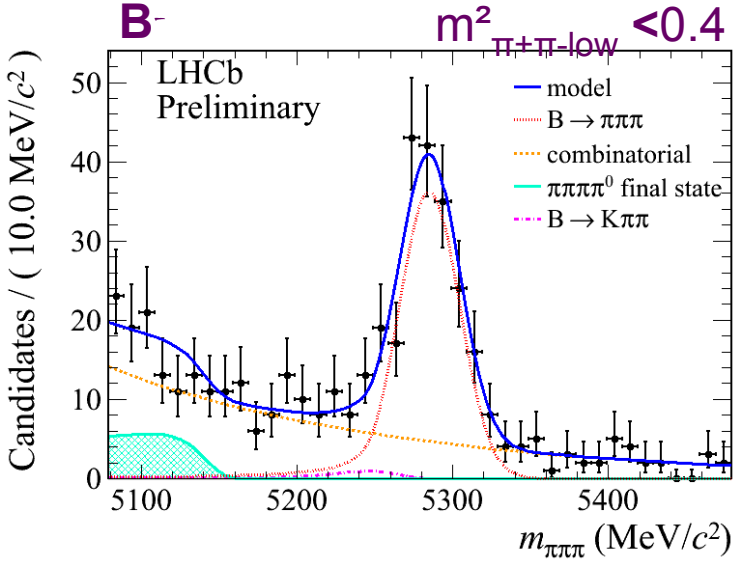
CKM2012
Cincinnati, 28/SET-2/OCT *±40MeV m_B mass window

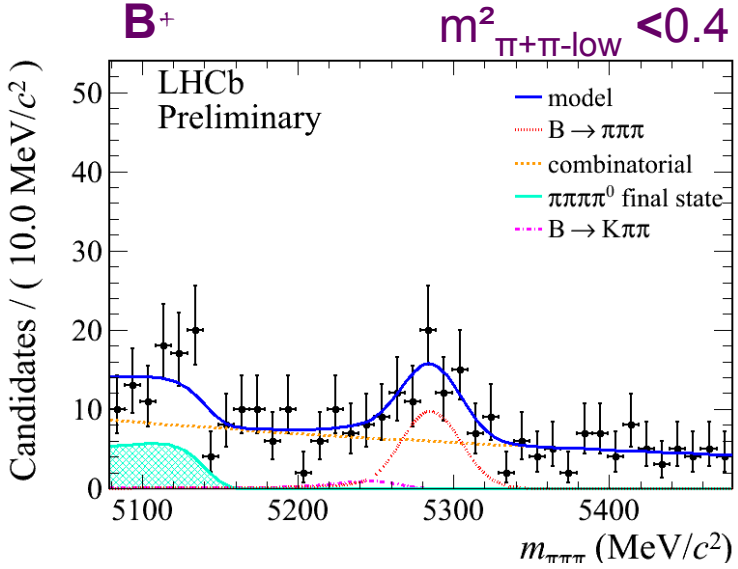
$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ zoom in the large CP region

preliminary LHCb-CONF-2012-028



very large positive CP in a region of the phase space not associated to a resonance

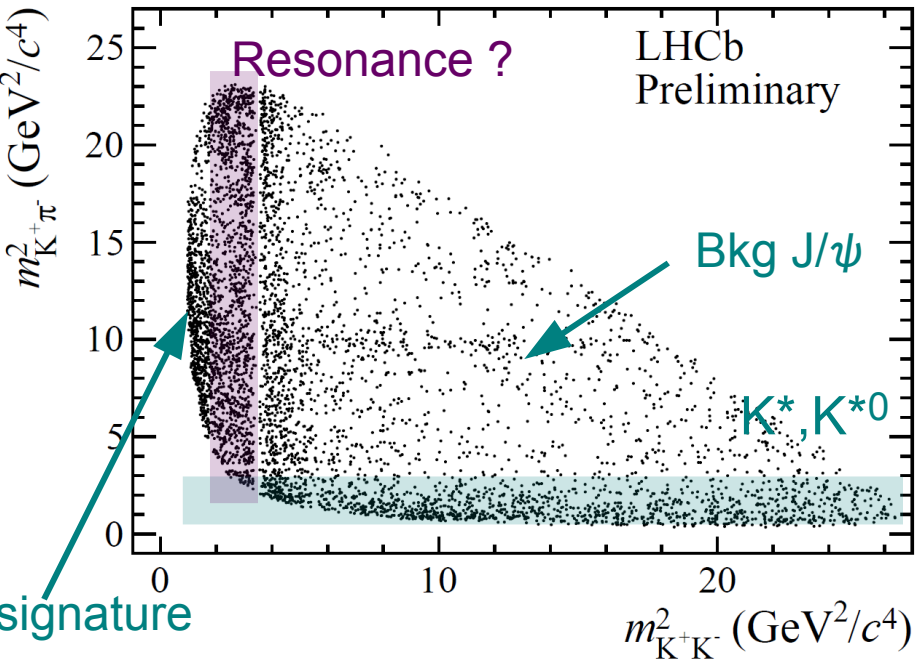




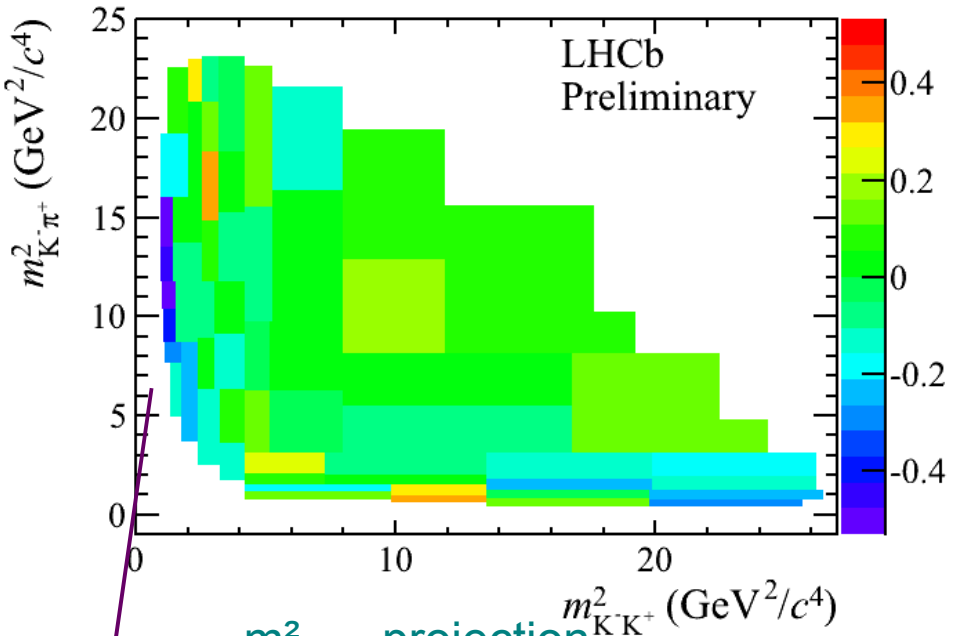
$$A_{CP}(B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-} \text{ region}) = +0.622 \pm 0.075(\text{stat}) \pm 0.032(\text{syst}) \pm 0.007(J/\psi K^{\pm})$$

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

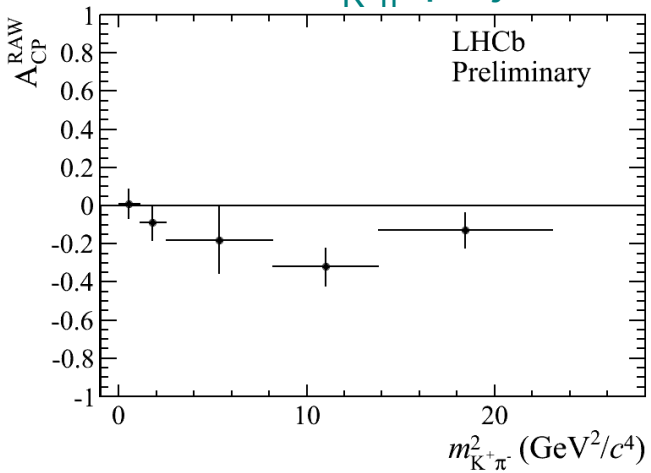
preliminary LHCb-CONF-2012-028



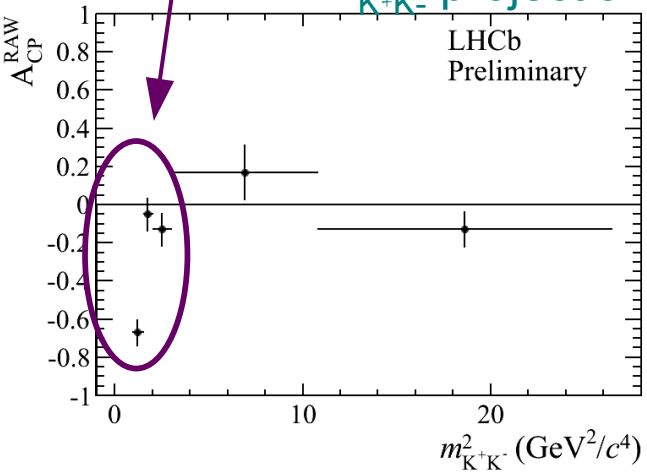
- asymmetry in the number of events:
  $A \equiv (N^- - N^+)/(N^- + N^+)$; N=sig+bkg
- equal population binning



$m^2_{K^+\pi^-}$ projection



$m^2_{K^+K^-}$ projection

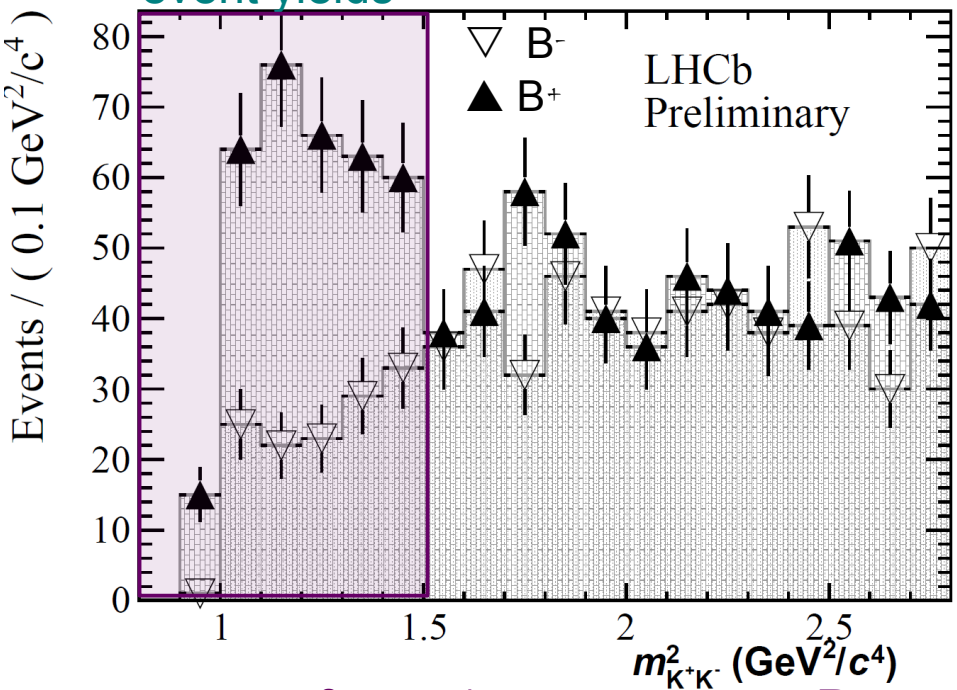


*±40MeV m_B mass window

$B^{\pm} \to \pi^{\pm} K^{+} K^{-}$ zoom in the large $\not{C}P$ region

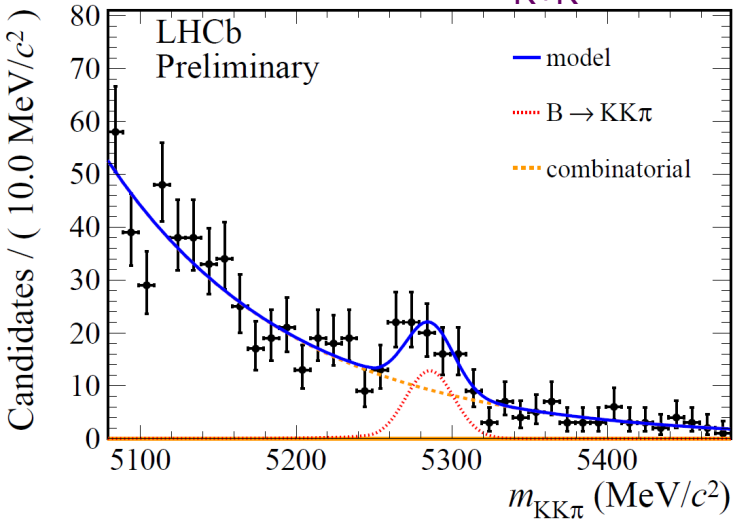
preliminary LHCb-CONF-2012-028

event yields

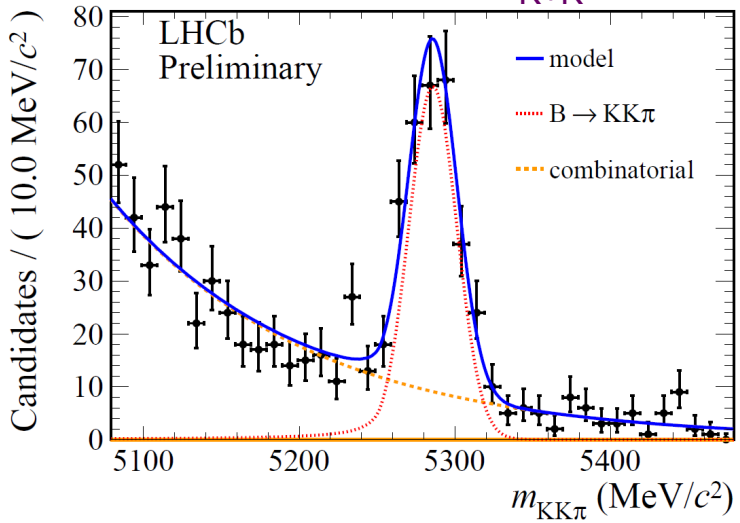


very large **negative** $\not{C}P$ in a region of the phase space not associated to a resonance

B^{-} $m^2_{K+K-} < 1.5$



B^{+} $m^2_{K+K-} < 1.5$



$$A_{CP}(B^{\pm} \to K^{+}K^{-}\pi^{\pm} \text{ region}) = -0.671 \pm 0.067(\text{stat}) \pm 0.028(\text{syst}) \pm 0.007(J/\psi\, K^{\pm})$$

- $\not{CP}$ observed in all 4 channels
- large $\not{CP}$ in $B^{\pm} \rightarrow \pi^{\pm}K^{+}K^{-}$ and $B^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ ($\propto\lambda^3$, $\propto\lambda^3$) as compared to $B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \rightarrow K^{\pm}K^{+}K^{-}$ ($\propto\lambda^4$, $\propto\lambda^2$) •• similar pattern observed in the two body decays for $B_s^0 \rightarrow K^{-}\pi^{+}$ and $B^0 \rightarrow K^{+}\pi^{-}$
- positive $\not{CP}$ in $B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ •• negative in $B^{\pm} \rightarrow \pi^{\pm}K^{+}K^{-}$ and $B^{\pm} \rightarrow K^{\pm}K^{+}K^{-}$
- $\not{CP}$ not uniform in the dalitz plot •• large $\not{CP}$ in the low $K^{+}K^{-}$ and $\pi^{+}\pi^{-}$ invariant mass regions •• no evidence of large $\not{CP}$ elsewhere.
- $\not{CP}$ do not follow usual resonance structure •• future amplitude analysis will need to incorporate this feature.

conclusion

- first **evidence** of direct $\not{CP}$ in $B_s^0 \to K^- \pi^+$ and precision at $B^0 \to K^+ \pi^-$
  PRL **108**,201601(2012) **L= 0.35 fb^{-1}**

$$A_{CP}(B^0 \to K\pi) = -0.088 \pm 0.011(\text{stat}) \pm 0.008(\text{syst}) \quad >6\sigma$$

$$A_{CP}(B_s^0 \to K\pi) = 0.27 \pm 0.08(\text{stat}) \pm 0.02(\text{syst}). \quad 3.3\sigma$$

- **evidence** of direct $\not{CP}$ in $B^\pm \to K^\pm \pi^+\pi^-$ and $B^\pm \to K^\pm K^+ K^-$
  LHCb-CONF-2012-018 **preliminary** **L= 1.0 fb^{-1}**

$$A_{CP}(B^\pm \to K^\pm\pi^+\pi^-) = +0.034 \pm 0.009(\text{stat}) \pm 0.004(\text{syst}) \pm 0.007(J/\psi K^\pm), \quad 2.8\sigma$$

$$A_{CP}(B^\pm \to K^\pm K^+ K^-) = -0.046 \pm 0.009(\text{stat}) \pm 0.005(\text{syst}) \pm 0.007(J/\psi K^\pm) \quad 3.7\sigma$$

  - large $\not{CP}$ in regions of the dalitz plot

- **evidence** of direct $\not{CP}$ in $B^\pm \to \pi^\pm K^+ K^-$ and $B^\pm \to \pi^\pm\pi^+\pi^-$ **new**
  LHCb-CONF-2012-028 **preliminary** **L= 1.0 fb^{-1}**

$$A_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-) = +0.120 \pm 0.020(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K^\pm) \quad 4.2\sigma$$

$$A_{CP}(B^\pm \to K^+K^-\pi^\pm) = -0.153 \pm 0.046(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K^\pm) \quad 3.0\sigma$$

  - very large $\not{CP}$ in regions of the dalitz plot

$$A_{CP}(B^\pm \to \pi^\pm\pi^+\pi^- \text{ region}) = +0.622 \pm 0.075(\text{stat}) \pm 0.032(\text{syst}) \pm 0.007(J/\psi K^\pm) \quad >7\sigma$$

$$A_{CP}(B^\pm \to K^+K^-\pi^\pm \text{ region}) = -0.671 \pm 0.067(\text{stat}) \pm 0.028(\text{syst}) \pm 0.007(J/\psi K^\pm) \quad >9\sigma$$

expect ~triple the sample with 2012 data

TABLE II. Summary of systematic uncertainties on $A_{CP}(B^0 \to K\pi)$ and $A_{CP}(B_s^0 \to K\pi)$. The categories (a), (b), and (c) defined in the text are also indicated. The total systematic uncertainties given in the last row are obtained by summing the individual contributions in quadrature.

Systematic uncertainty	$A_{CP}(B^0 \to K\pi)$	$A_{CP}(B_s^0 \to K\pi)$
(a) PID calibration	0.0012	0.001
(b) Final state radiation	0.0026	0.010
(b) Signal model	0.0004	0.005
(b) Combinatorial background	0.0001	0.009
(b) 3-body background	0.0009	0.007
(b) Cross-feed background	0.0011	0.008
(c) Instr. and prod. asym. (A_Δ)	0.0078	0.005
Total	0.0084	0.019

Table 2: Systematic uncertainties to the A_{CP} measurements for $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \to K^{\pm}K^{+}K^{-}$. The totals are the sums in quadrature of the contributions.

Contribution	$K^{\pm}\pi^{+}\pi^{-}$	$K^{\pm}K^{+}K^{-}$
Signal fixed parameters	0.002	0.002
Signal model	0.0001	0.0001
Signal shape	0.0012	0.0001
Background model	0.0003	0.00002
Background asymmetry	0.0002	0.0001
Acceptance	0.001	0.0015
Trigger correction	0.0011	0.001
Subtraction method	0.003	0.004
Total	0.004	0.005

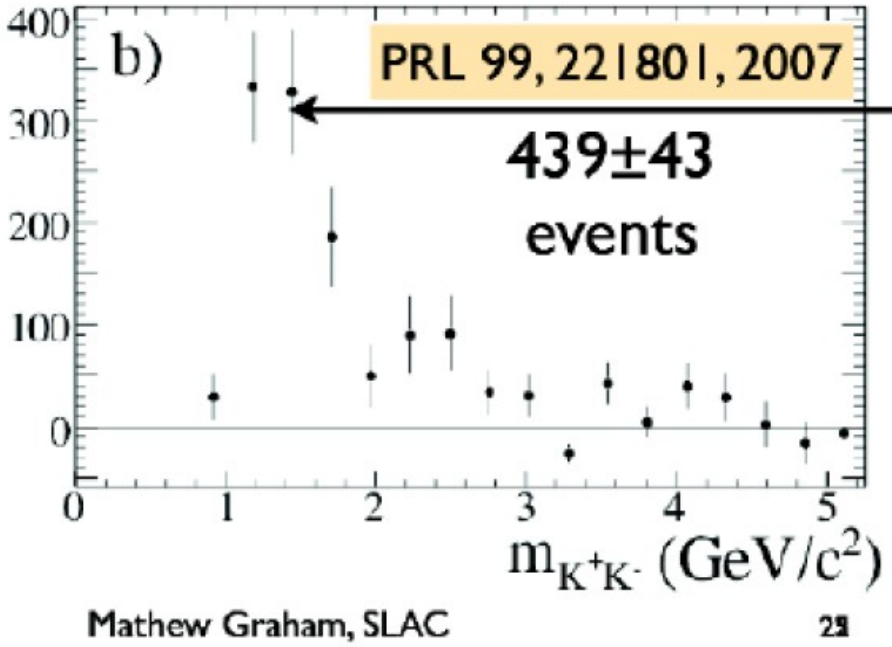
Table 2: Summary of the systematic uncertainties to the A_{CP} measurements. The totals are the sums in quadrature of the contributions.

Contribution	$\pi\pi\pi$	$KK\pi$
Fit function model	0.008	0.009
Acceptance	0.015	0.014
$A_{\rm D}^{K}$ kaon kinematics	0.008	0.008
$A_{\rm D}^{K}$ stat. uncertainty	0.002	0.002
$A_{\rm D}^{\pi}$ stat. uncertainty	0.003	0.003
Total	0.019	0.019

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

Surprisingly large rate seen in $B^+ \to K^+K^-\pi^+$; no evidence for $\varphi\pi^+$

$$\mathcal{B}(B^+ \to K^+K^-\pi^+) = (5.0 \pm 0.5 \pm 0.5) \times 10^{-6}$$



~ 1/2 of the events seen at low K^+K^- mass; structure at ~1.5GeV?
Similar broad structures seen in $K^+K^-K^+/K^+K^-K_S$ and $\pi^+\pi^-K^+/\pi^+\pi^-K_S$

What about $K_SK_S\pi^+$?

Matt Graham
SLAC
on behalf of the BaBar Collaboration
February 12, 2009
Aspen Winter Conference

$$A_{CP} = A_{raw} - \zeta_{d(s)} A_D(K\pi) - \kappa_{d(s)} A_P(B^0_{(s)})$$

- **instrumental** from D* and untagged D→ hh

  $\zeta_d = 1 \quad \zeta_s = -1.$

  $A_D = -0.010 \pm 0.02$

- $B^0_{(s)}$ -$\bar{B}^0_{(s)}$ **mixing**

  $\kappa_d = 0.303 \pm 0.005$

  $\kappa_s = -0.033 \pm 0.003$ ●● small

- **production** from $B^\ominus \to J/\psi K^{*\ominus}$

  $A_P(B^0) = 0.010 \pm 0.013$

  negligible for $B_s^\ominus$

total corrections

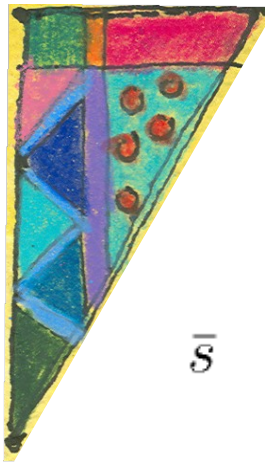
$$A_\Delta(B^0 \to K\pi) = -0.007 \pm 0.006$$
$$A_\Delta(B_s^0 \to K\pi) = 0.010 \pm 0.002$$

$$A_{CP}(B^0 \to K\pi) = -0.088 \pm 0.011(\text{stat}) \pm 0.008(\text{syst})$$

most precise >6σ

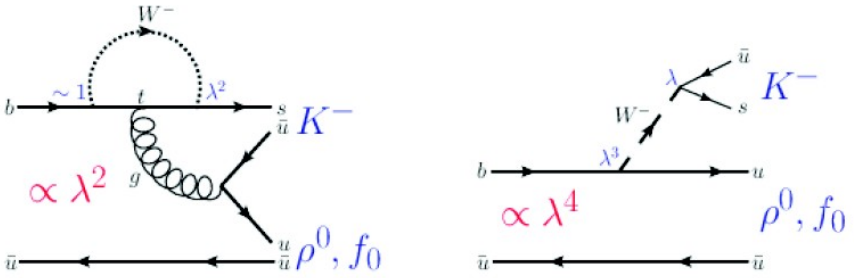
$$A_{CP}(B_s^0 \to K\pi) = 0.27 \pm 0.08(\text{stat}) \pm 0.02(\text{syst}).$$

first evidence 3.3σ

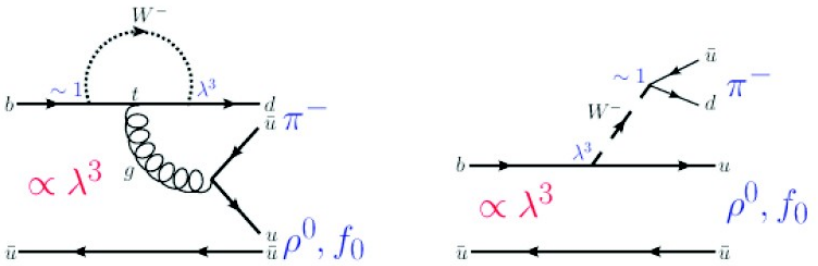


$\bar{s}$

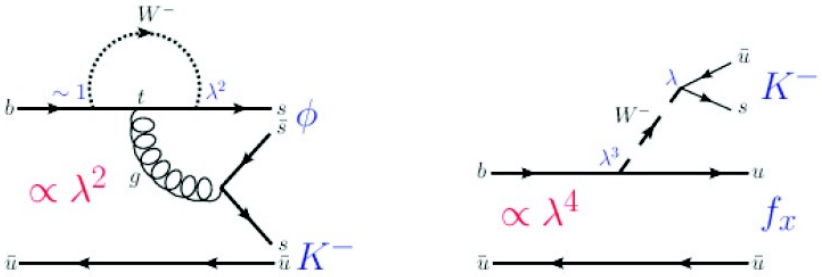
$B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$



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



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



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