Methods to determine weak phases from charmless Dalitz plots – an experimental perspective

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2^{nd} B2TIP meeting; Krakow

29 April 2015

A potential treasure trove

- There is a lot of discussion about discrepancies in flavour physics that may stay or may go with more data
- However, there are (at least three) that will certainly stay
  - The πK puzzle
  - CP violation in $B \to 3h$
  - The $B \to VV$ polarisation puzzle
- These can, of course, all be argued away (not explained) by QCD, but let's hope to do better

Contents

- $B \to \pi\pi\pi$
- $B \to K\pi\pi$
-

Snyder-Quinn method for α

PHYSICAL REVIEW D VOLUME 48, NUMBER 5 1 SEPTEMBER 1993

Measuring *CP* asymmetry in $B \rightarrow \rho\pi$ decays without ambiguities

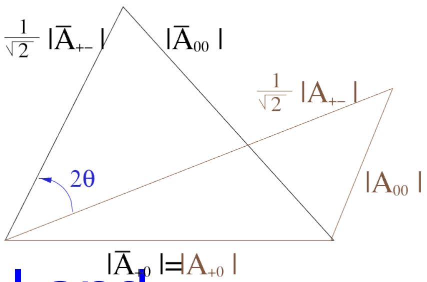
PRD 48 (1993) 2139

Arthur E. Snyder and Helen R. Quinn
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309
(Received 24 February 1993)

- Methods to measure α exploit time-dependent CP violation in B_d decays via $b \rightarrow u$ transitions (eg. $B_d \rightarrow \pi^+\pi^-$)

PRL 65 (1990) 3381

- Penguin "pollution" can be subtracted using Gronau-London isospin triangles built from $A(\pi^+\pi^-)$, $A(\pi^+\pi^0)$, $A(\pi^0\pi^0)$



- Expect discrete ambiguities in the solution for α
- Ambiguities can be resolved if you measure both real and imaginary parts of $\lambda = (q/p)(\bar{A}/A)$
  - ie. measure cos(2α) as well as sin(2α)

Toy model for $B \to \pi^+\pi^-\pi^0$ Dalitz plot

Contributions only from $\rho^+\pi^-$, $\rho^-\pi^+$ and $\rho^0\pi^0$

PRD 48 (1993) 2139

27 parameters renamed "U" and "I" in commonly used notation

H.Quinn and J.Silva, PRD 62 (2000) 054002

TABLE I. The time and kinematic dependence of contributions to the distribution of events.

Time dependence	Kinematic form	Amplitude measured	α dependence (all $P_i=0$)
1	f^+f^{+*}	$S_3S_3^* + \bar{S}_4\bar{S}_4^*$	1
$\cos(\Delta M t)$	f^+f^{+*}	$S_3S_3^* - \bar{S}_4\bar{S}_4^*$	1
$\sin(\Delta M t)$	f^+f^{+*}	$\mathrm{Im}(q\bar{S}_4S_3^*)$	$\sin(2\alpha)$
1	f^-f^{-*}	$S_4S_4^* + \bar{S}_3\bar{S}_3^*$	1
$\cos(\Delta M t)$	f^-f^{-*}	$S_4S_4^* - \bar{S}_3\bar{S}_3^*$	1
$\sin(\Delta M t)$	f^-f^{-*}	$\mathrm{Im}(q\bar{S}_3S_4^*)$	$\sin(2\alpha)$
1	f^0f^{0*}	$(S_5S_5^* + \bar{S}_5\bar{S}_5^*)/4$	1
$\cos(\Delta M t)$	f^0f^{0*}	$(S_5S_5^* - \bar{S}_5\bar{S}_5^*)/4$	1
$\sin(\Delta M t)$	f^0f^{0*}	$\mathrm{Im}(q\bar{S}_5S_5^*)/4$	$\sin(2\alpha)$
1	$\mathrm{Re}(f^+f^{-*})$	$\mathrm{Re}(S_3S_4^* + \bar{S}_4\bar{S}_3^*)$	1
$\cos(\Delta M t)$	$\mathrm{Re}(f^+f^{-*})$	$\mathrm{Re}(S_3S_4^* - \bar{S}_4\bar{S}_3^*)$	1
$\sin(\Delta M t)$	$\mathrm{Re}(f^+f^{-*})$	$\mathrm{Im}(q\bar{S}_4S_4^* - q^*S_3\bar{S}_3^*)$	$\sin(2\alpha)$
1	$\mathrm{Im}(f^+f^{-*})$	$\mathrm{Im}(S_3S_4^* + \bar{S}_4\bar{S}_3^*)$	1
$\cos(\Delta M t)$	$\mathrm{Im}(f^+f^{-*})$	$\mathrm{Im}(S_3S_4^* - \bar{S}_4\bar{S}_3^*)$	1
$\sin(\Delta M t)$	$\mathrm{Im}(f^+f^{-*})$	$\mathrm{Re}(q\bar{S}_4S_4^* - q^*S_3\bar{S}_3^*)$	$\cos(2\alpha)$
1	$\mathrm{Re}(f^+f^{0*})$	$\mathrm{Re}(S_3S_5^* + \bar{S}_4\bar{S}_5^*)/2$	1
$\cos(\Delta M t)$	$\mathrm{Re}(f^+f^{0*})$	$\mathrm{Re}(S_3S_5^* - \bar{S}_4\bar{S}_5^*)/2$	1
$\sin(\Delta M t)$	$\mathrm{Re}(f^+f^{0*})$	$\mathrm{Im}(q\bar{S}_4S_5^* + q^*S_3\bar{S}_5^*)/2$	$\sin(2\alpha)$
1	$\mathrm{Im}(f^+f^{0*})$	$\mathrm{Im}(S_3S_5^* + \bar{S}_4\bar{S}_5^*)/2$	1
$\cos(\Delta M t)$	$\mathrm{Im}(f^+f^{0*})$	$\mathrm{Im}(S_3S_5^* - \bar{S}_4\bar{S}_5^*)/2$	1
$\sin(\Delta M t)$	$\mathrm{Im}(f^+f^{0*})$	$\mathrm{Re}(q\bar{S}_4S_5^* - q^*S_3\bar{S}_5^*)/2$	$\cos(2\alpha)$
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$\cos(\Delta M t)$	$\mathrm{Re}(f^-f^{0*})$	$\mathrm{Re}(S_4S_5^* - \bar{S}_3\bar{S}_5^*)/2$	1
$\sin(\Delta M t)$	$\mathrm{Re}(f^-f^{0*})$	$\mathrm{Im}(q\bar{S}_3S_5^* - q^*S_4\bar{S}_5^*)$	$\sin(2\alpha)$
1	$\mathrm{Im}(f^-f^{0*})$	$\mathrm{Im}(S_4S_5^* + \bar{S}_3\bar{S}_5^*)/2$	1
$\cos(\Delta M t)$	$\mathrm{Im}(f^-f^{0*})$	$\mathrm{Im}(S_4S_5^* - \bar{S}_3\bar{S}_5^*)/2$	1
$\sin(\Delta M t)$	$\mathrm{Im}(f^-f^{0*})$	$\mathrm{Re}(q\bar{S}_3S_5^* - q^*S_4\bar{S}_5^*)/2$	$\cos(2\alpha)$

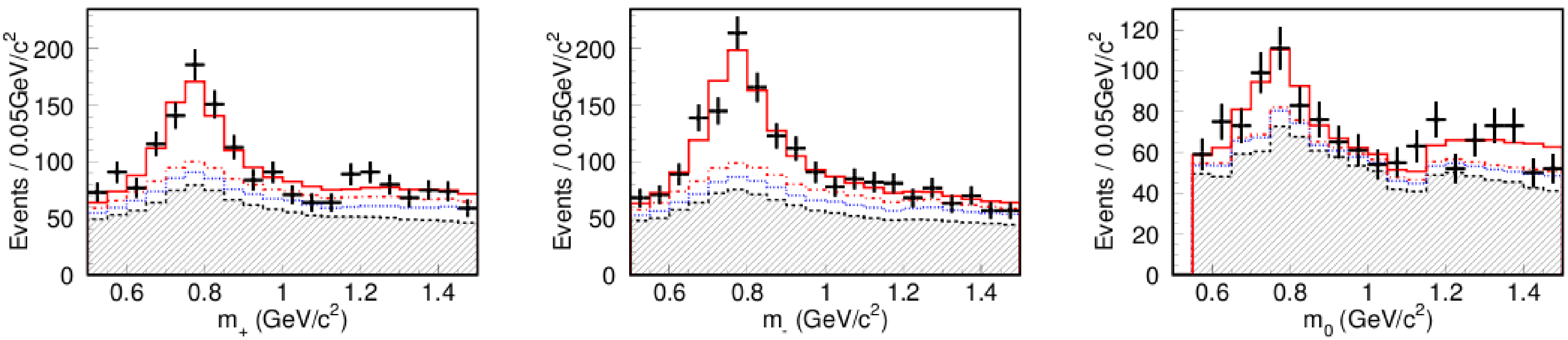
Note: physical observables depend on either sin(2α) or cos(2α) – never "directly" on α

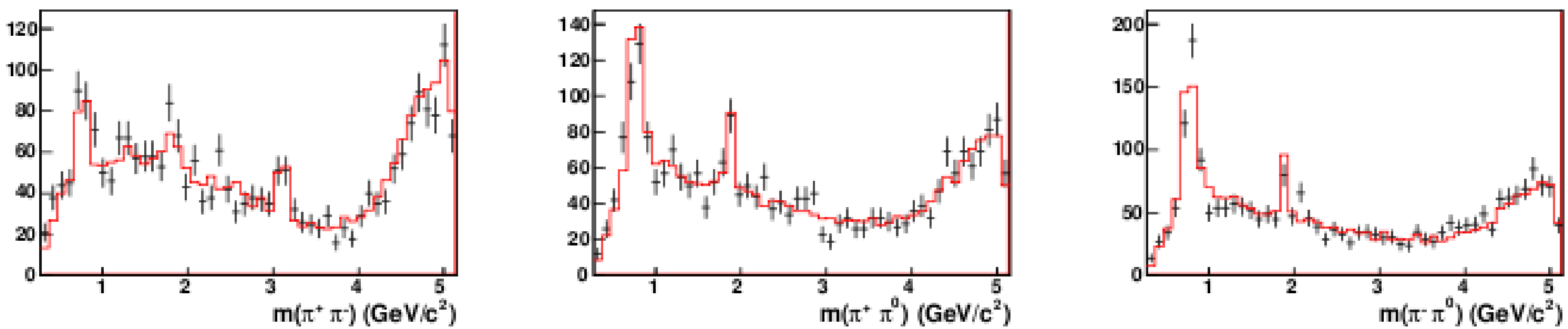
f terms contain hadronic physics (lineshape, spin)

$S_3 = A(\rho^+\pi^-)$, $S_4 = A(\rho^-\pi^+)$, $S_5 = A(\rho^0\pi^0)$,

$B \to \pi^+\pi^-\pi^0$ – B factory results

- Results from
  - Belle, 449 M BB pairs: PRL 98 (2007) 221602, PRD 77 (2008) 072001
  - BaBar, 471 M BB pairs: PRD 88 (2013) 012003





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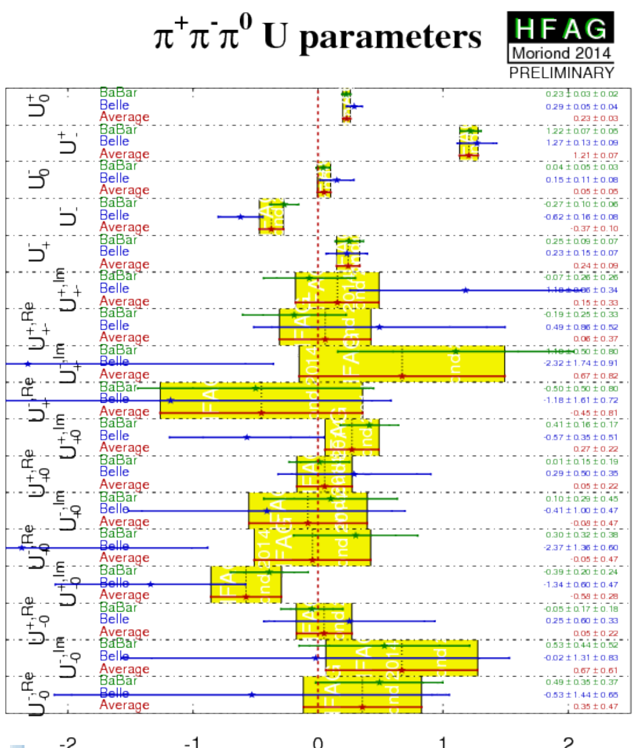

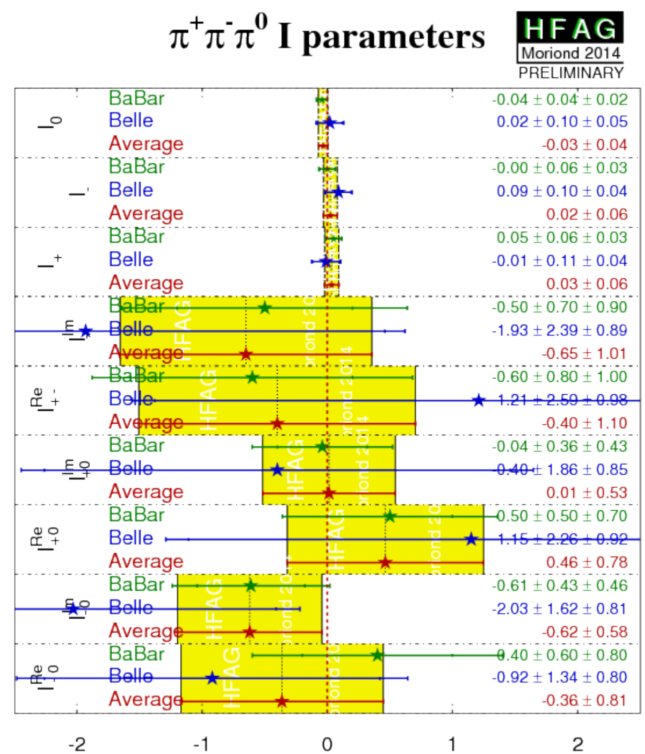

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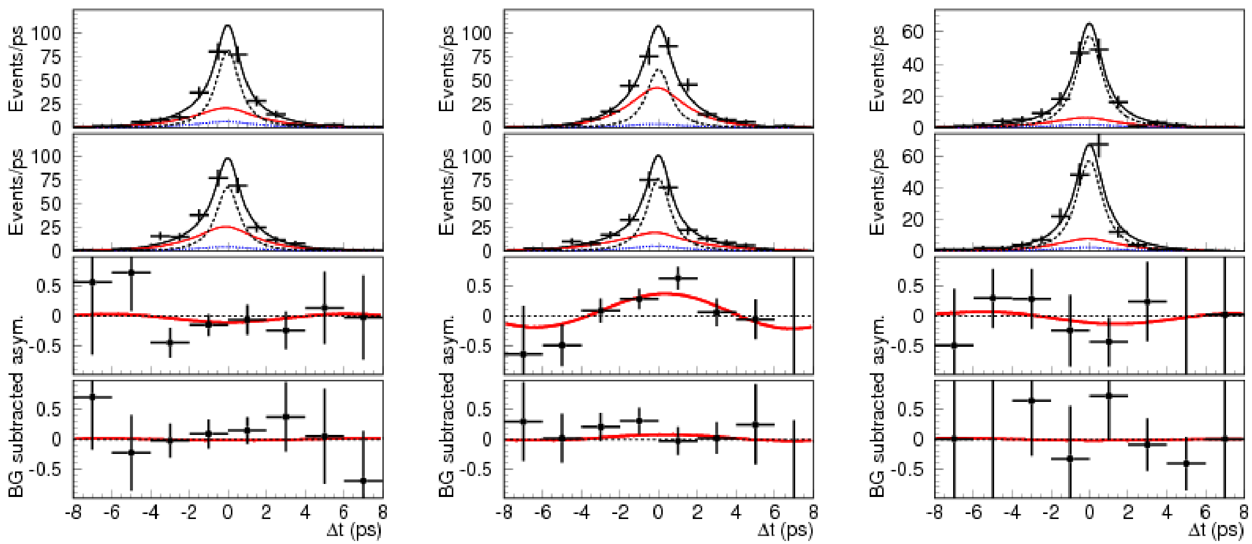

FIG. 10: Proper time distributions of good tag ($r > 0.5$) regions for $f_{\rm tag} = B^0$ (upper) and $f_{\rm tag} = \overline{B}^0$ (middle upper), in $\rho^+\pi^-$ (left), $\rho^-\pi^+$ (middle), $\rho^0\pi^0$ (right) enhanced regions, where solid (red), dotted, and dashed curves correspond to signal, continuum, and $B\overline{B}$ PDFs. The middle lower and lower plots show the background-subtracted asymmetries in the good tag ($r > 0.5$) and poor tag ($r < 0.5$) regions, respectively. The significant asymmetry in the $\rho^-\pi^+$ enhanced region (middle) corresponds to a non-zero value of U^-_-.

$\rho^+\pi^-$ $\rho^-\pi^+$ $\rho^0\pi^0$

$B \to \pi^+\pi^-\pi^0$ – B factory results

- Results from
  - Belle, 449 M BB pairs: PRL 98 (2007) 221602, PRD 77 (2008) 072001
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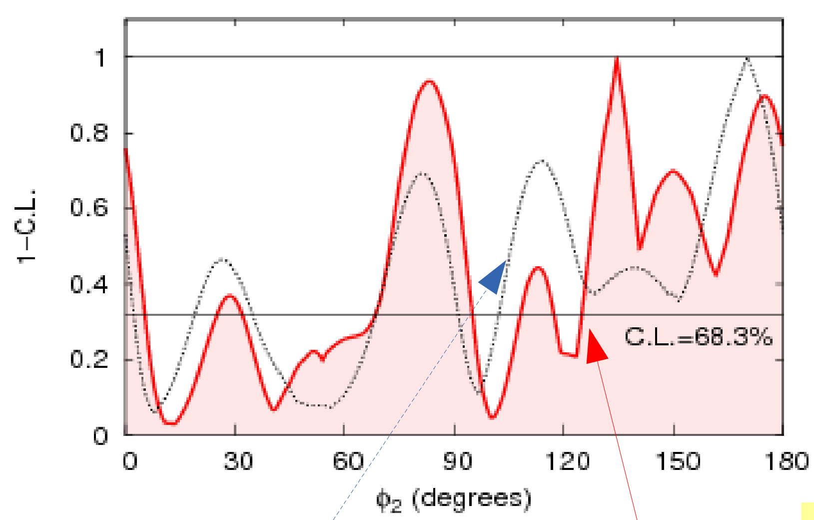
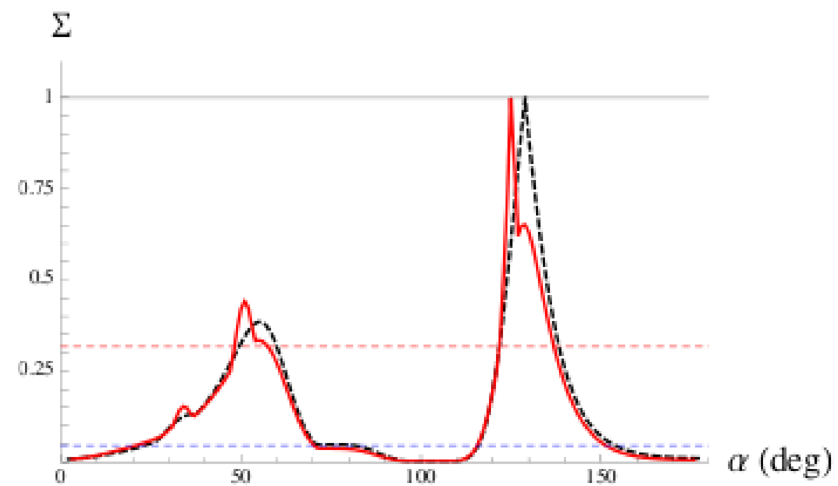




Contour from $B \to \pi^+\pi^-\pi^0$ only

"the extraction of α with our current sample size is not robust"

Including also information on $B^+ \to \rho^+\pi^0$ and $B^+ \to \rho^0\pi^+$

Comment on $B \to \pi^+\pi^-\pi^0$

- It is not clear (to me) whether the current sensitivity to α can be extrapolated
  - are we just measuring fluctuations?
- It has been observed that $D \to \pi^+\pi^-\pi^0$ is close to pure CP-even
  - maybe there is a fundamental reason for this
  - maybe it is relevant also for $B \to \pi^+\pi^-\pi^0$?
  - if so, what is the impact on the Snyder-Quinn method to measure α?

$B \to K\pi\pi$

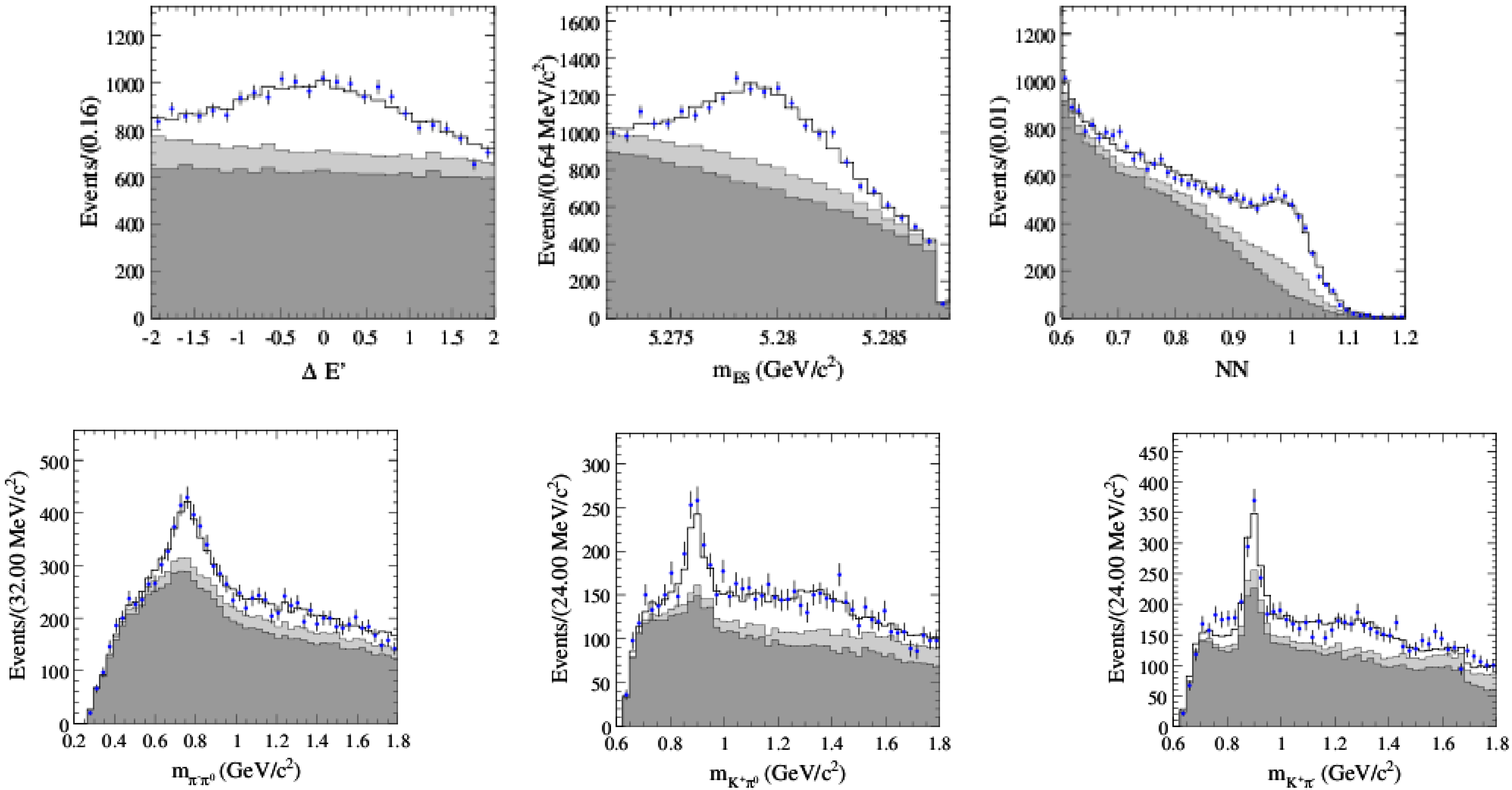
- PRD 74 (2006) 051301, PRD 75 (2007) 014002

$$\mathcal{A}_{\frac{3}{2}}(K^*\pi) = \frac{1}{\sqrt{2}}\mathcal{A}(B^0 \to K^{*+}\pi^-) + \mathcal{A}(B^0 \to K^{*0}\pi^0).$$

- Construct pure I=3/2 amplitude for B and $\overline{B}$
  - Dalitz plot analysis of $B^0 \to K^+\pi^-\pi^0$
- Relative phase between B and $\overline{B}$ gives γ
  - Dalitz plot analysis of $B^0 \to K_S\pi^+\pi^-$
  - corrections due to electroweak penguins

BaBar PRD83 (2011) 112010

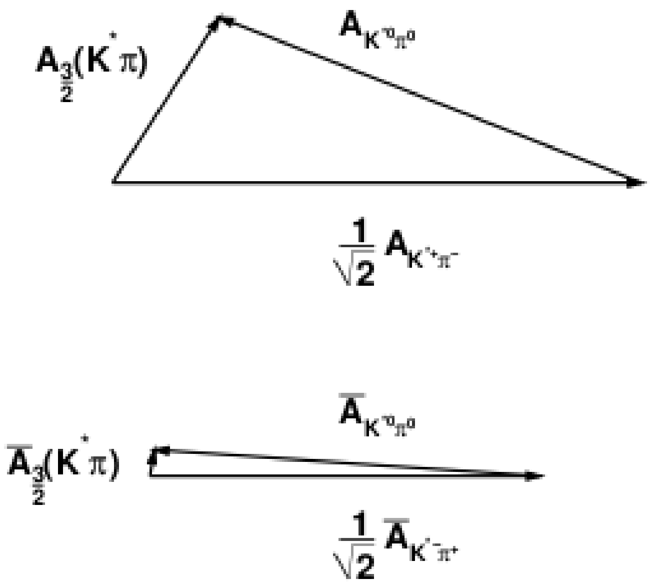
$B^0 \to K^+\pi^-\pi^0$

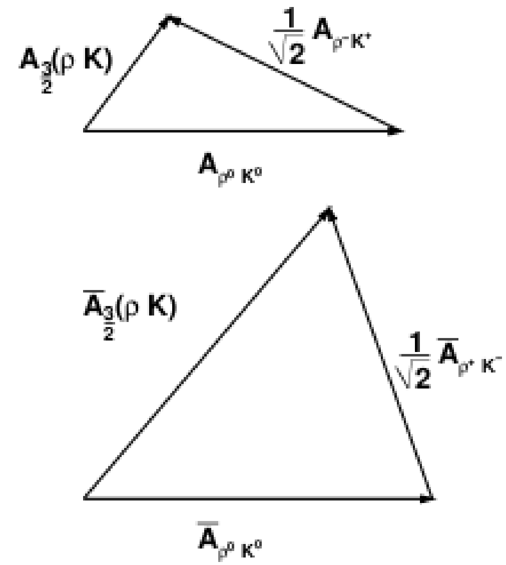


BaBar PRD83 (2011) 112010

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

Isospin triangles drawn to scale of experimental results but without uncertainties





Cancellation makes pure I=3/2 amplitude small – impossible to determine its relative phase

Method may work better for ρK amplitudes – but current uncertainty is large

The $B \to K\pi$ puzzle

- QCD may also be a cause of apparently anomalous CP violation effects

$$\Delta A_{CP}(K\pi) = A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0) \neq 0$$

	$A_{CP}(K^+\pi^-)$	$A_{CP}(K^+\pi^0)$	
	–0.082 ± 0.006 e.g. LHCb PRL 110 (2013) 221601	+0.040 ± 0.021 e.g. Belle PR D87 (2013) 031103	HFAG averages most precise single measurement

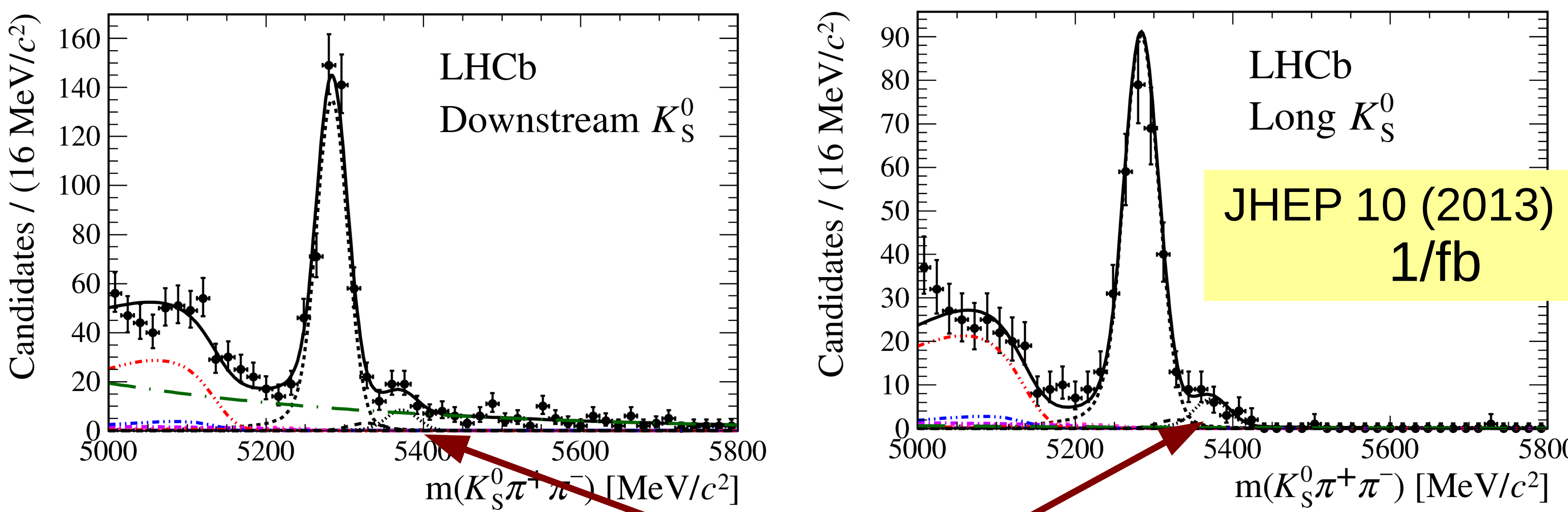
- Look for similar effects in $K^*\pi$ & $K\rho$ systems

$K^*\pi$	–0.23 ± 0.06 e.g. BaBar PR D83 (2011) 112010	–0.39 ± 0.13 e.g. BaBar arXiv:1501.00705
$K\rho$	+0.20 ± 0.11 e.g. BaBar PR D83 (2011) 112010	+0.37 ± 0.11 BaBar PR D78 (2008) 012004 & Belle PRL 96 (2006) 251803

Interesting pattern emerging? **Need new results from Belle & LHCb**

$B_s^0 \to K\pi\pi$?

- Same method works, in principle, for $B_s^0 \to K\pi\pi$
- Yields available are, however, small



JHEP 10 (2013) 143
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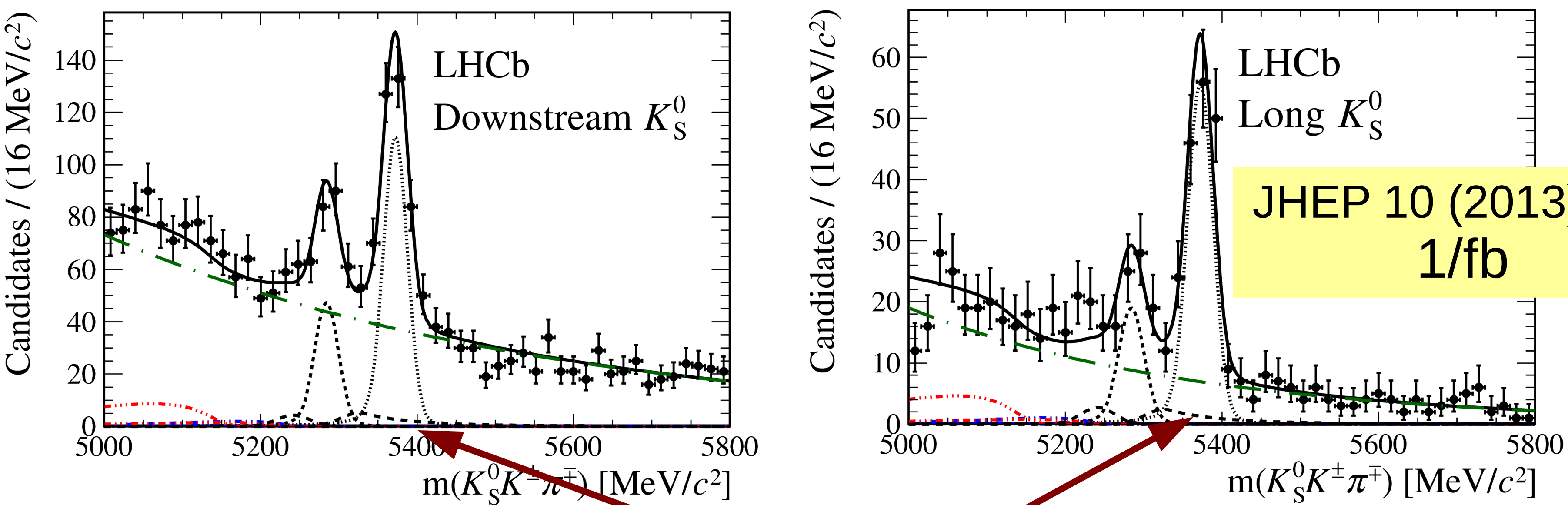
Observation of $B_s^0 \to K_S\pi^+\pi^-$

$B_s^0 \to KK\pi$?

- Similar method works, in principle, for $B_s^0 \to KK\pi$
- Reasonable yields available, but tagged time-dependent analysis necessary



JHEP 10 (2013) 143
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Observation of $B_s^0 \to K_S K^{+-} \pi^{-+}$

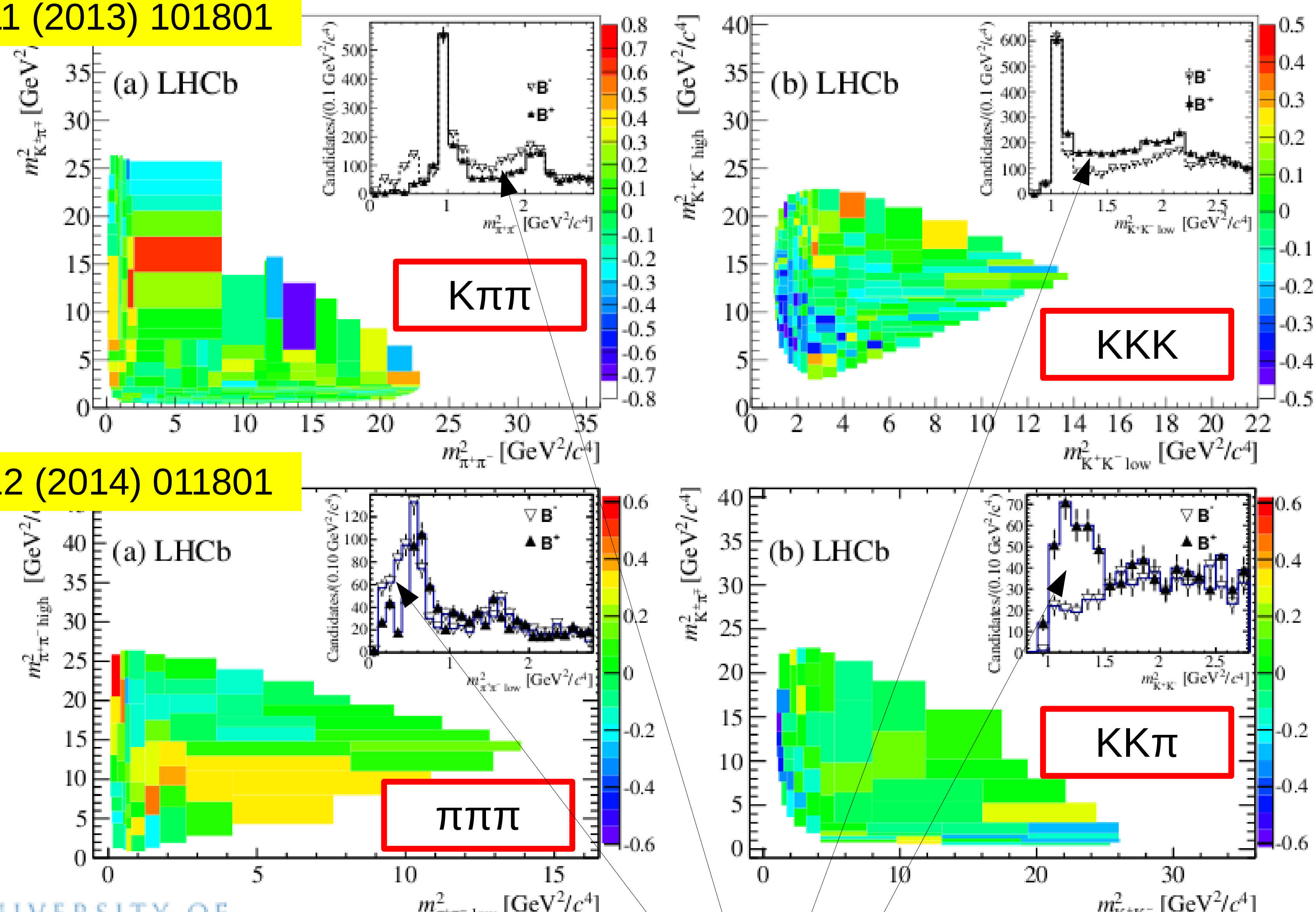
$B \to 3h$

- Experimentally, the most accessible decays are those with three final state tracks
- There is much literature on the possibility to measure weak phases through interference between charmless and charmonium contributions (however, not clean theoretically)
- Possibilities to use U-spin to relate decays
  - model-independent approaches
  - how to relate points in two different Dalitz plots?

CP violation in B→3h

PRL 111 (2013) 101801

PRL 112 (2014) 011801



Large CPV effects not associated with resonances – QCD effects to be understood

Summary

- Much physics potential in charmless hadronic decays …
  - and in three-body decays in particular
- Need smart methods to overcome hadronic uncertainties
- These often involve analyses of >1 Dalitz plot
  - much work needed!
- Some ideas for model-independent analyses
  - good DP modelling is nevertheless essential
- Many modes where sensitivity of Belle II is expected to surpass that of LHCb (but don't be complacent)