Time-independent γ measurements using $B^+ \rightarrow Dh^+$ at LHCb

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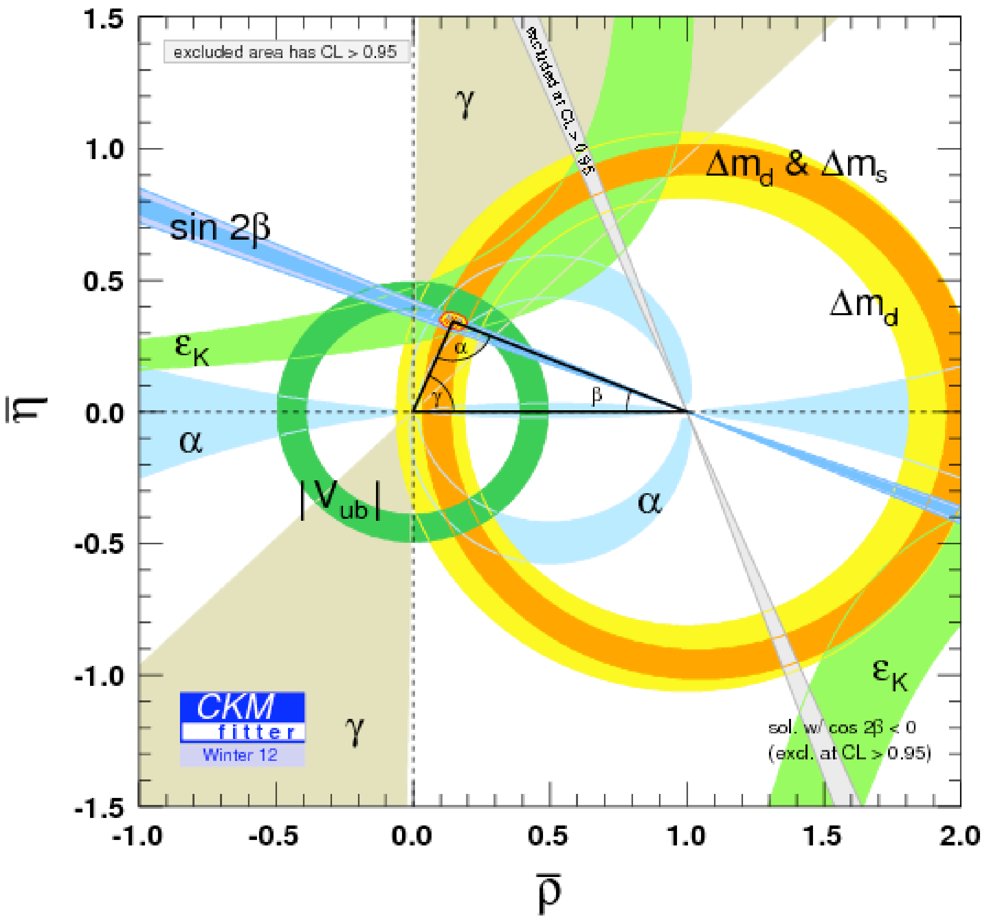
on behalf of the LHCb Collaboration

Current experimental status



CKM matrix parameterises quark couplings

$$\gamma = -\arg\left(\frac{V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}}\right)$$

Does $\alpha+\beta+\gamma$ = 180° ?

γ is the least well know angle

Precision measurement of γ can be achieved at LHCb

Goal: Measure γ in tree and loop decays

Overview for this talk

This talk gives the results using the following decays:

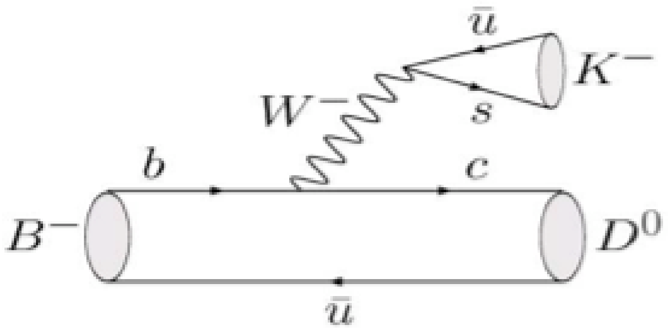
$B^+ \rightarrow Dh^+$, where h= K,π

$D \rightarrow K_s hh$, $D \rightarrow \pi\pi$, $D \rightarrow KK$, $D \rightarrow K\pi$, $D \rightarrow K\pi\pi\pi$

NEW RESULTS

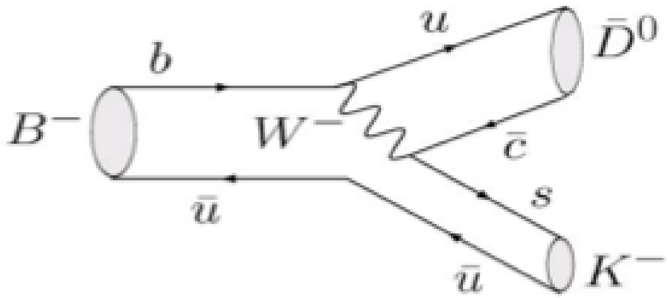
Other time independent results using $B^0 \rightarrow DK^*$, $B^0 \rightarrow DKK$
$B^+ \rightarrow DK\pi\pi$ covered in Mike Williams talk tomorrow (WG V)

B→DK decays



b → c (favoured)

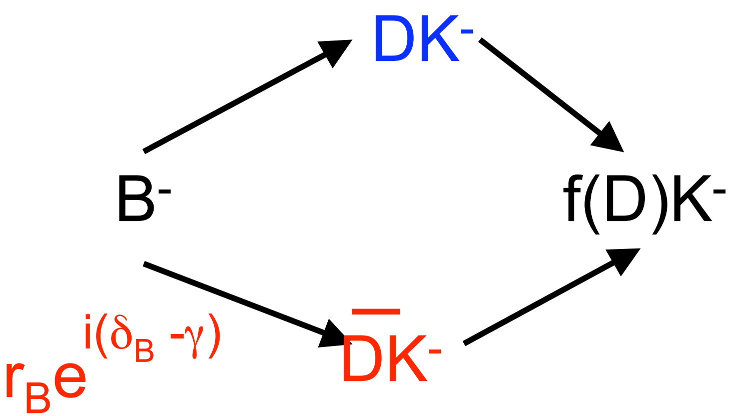
b → u (suppressed)



$$\gamma = -\arg\left(\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

Sensitivity to γ from b→c and b→u interference

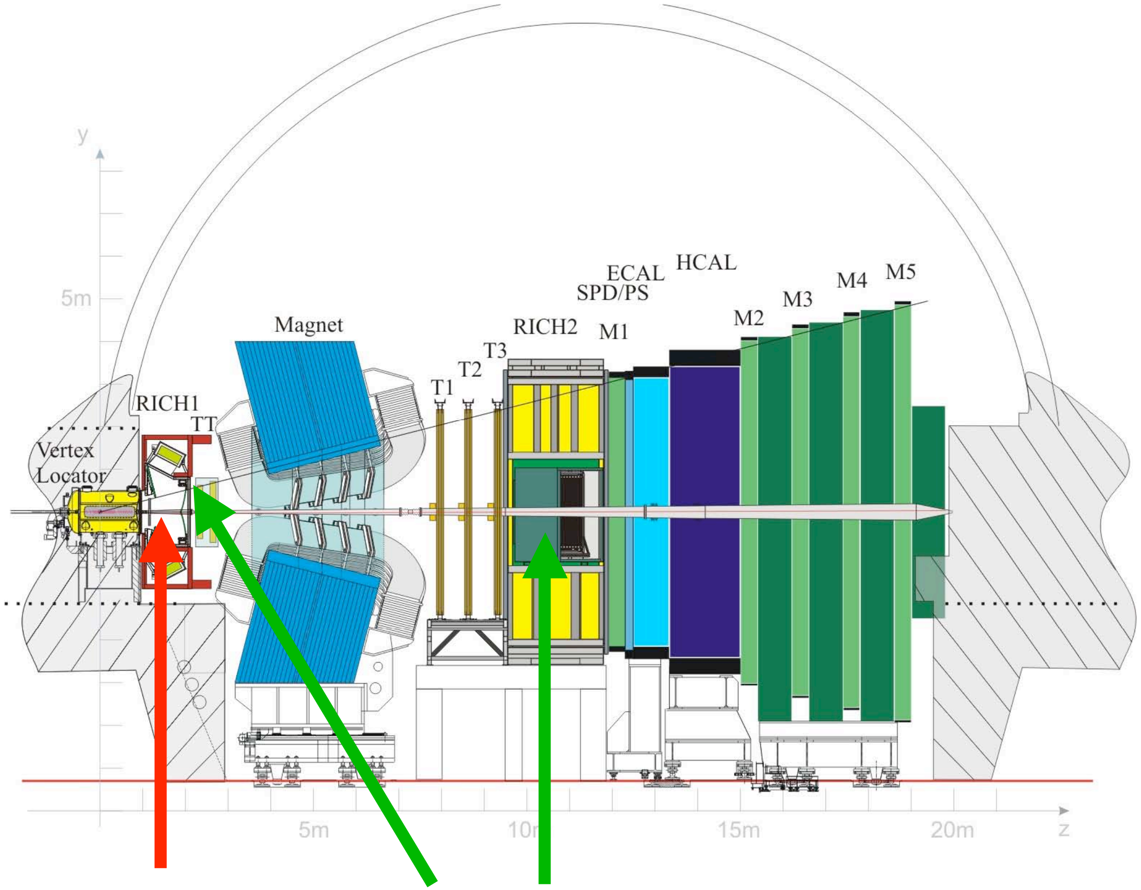
Require D^0 and $\bar{D}^0$ to decay to same final state



Number of D final states considered.

Similarities between modes - many common analysis themes in extracting the observables.

LHCb Detector



Vertex Locator RICH Detectors

Vertex Locator

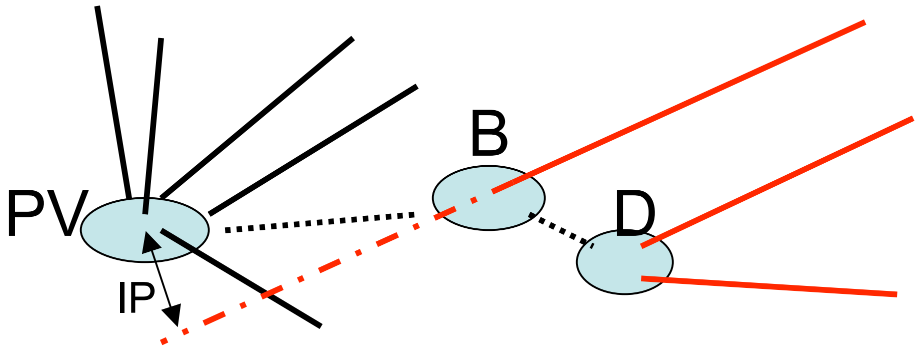
Find B and D secondary vertices

RICH Detectors

Provide separation between kaons and pions

Selection

Similar selection for each mode



Every mass hypothesis combination $B \rightarrow [X]_D h$, is reconstructed.

$h=K,\pi$; $X=hh^{(')},K\pi\pi\pi, K_S hh$

Analyses use full 2011 dataset 1.0 fb^{-1}.

Useful variables include:

•Transverse momenta

•Impact parameters

•Flight distances

•Vertex quality

Further selection applied to remove specific backgrounds

e.g Cut on D flight distance to remove charmless bkg like $B \rightarrow hhh$.

Vetos to remove other B decays, and misreconstructed D decays as necessary.

Mass parameterisation

Similar parameterisation used for all modes. Here I show the favoured D➔Kπ final state

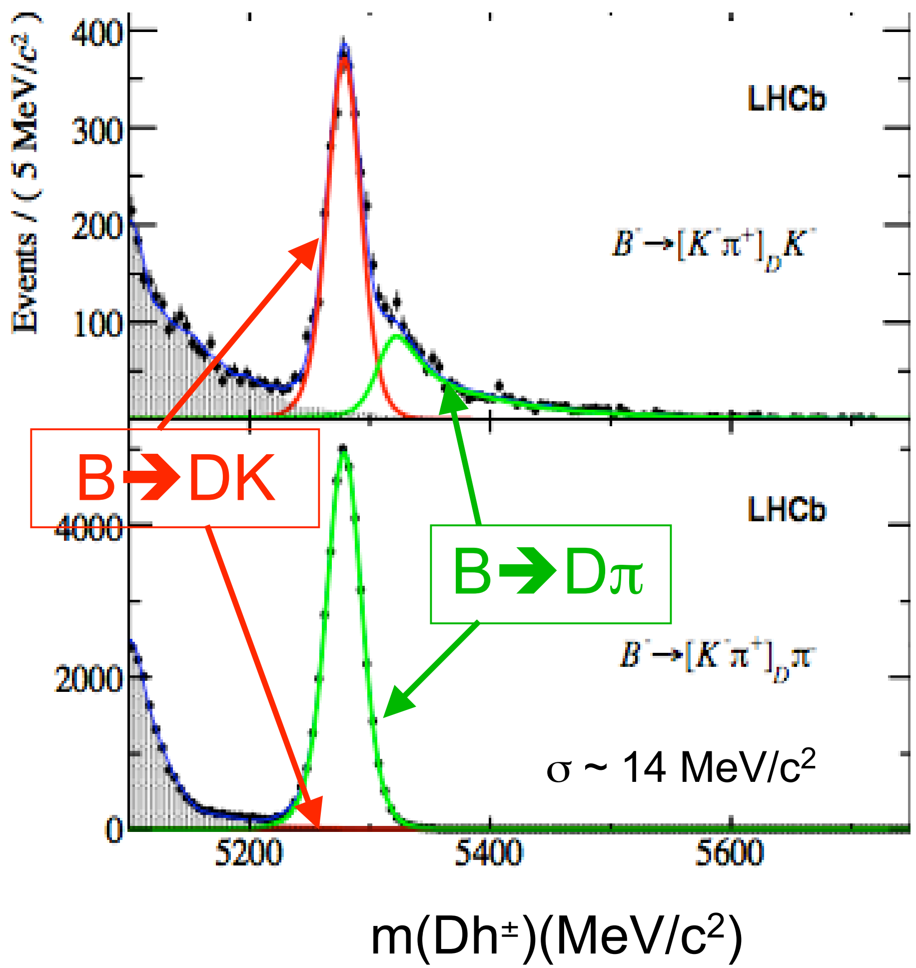
•Particle identification information on h from B divides the data.

•Favoured decay modes dominate statistics and constrain the shapes

•mis-ID rates fix the yield of the mis-ID component relative to the yield in the opposite plot.

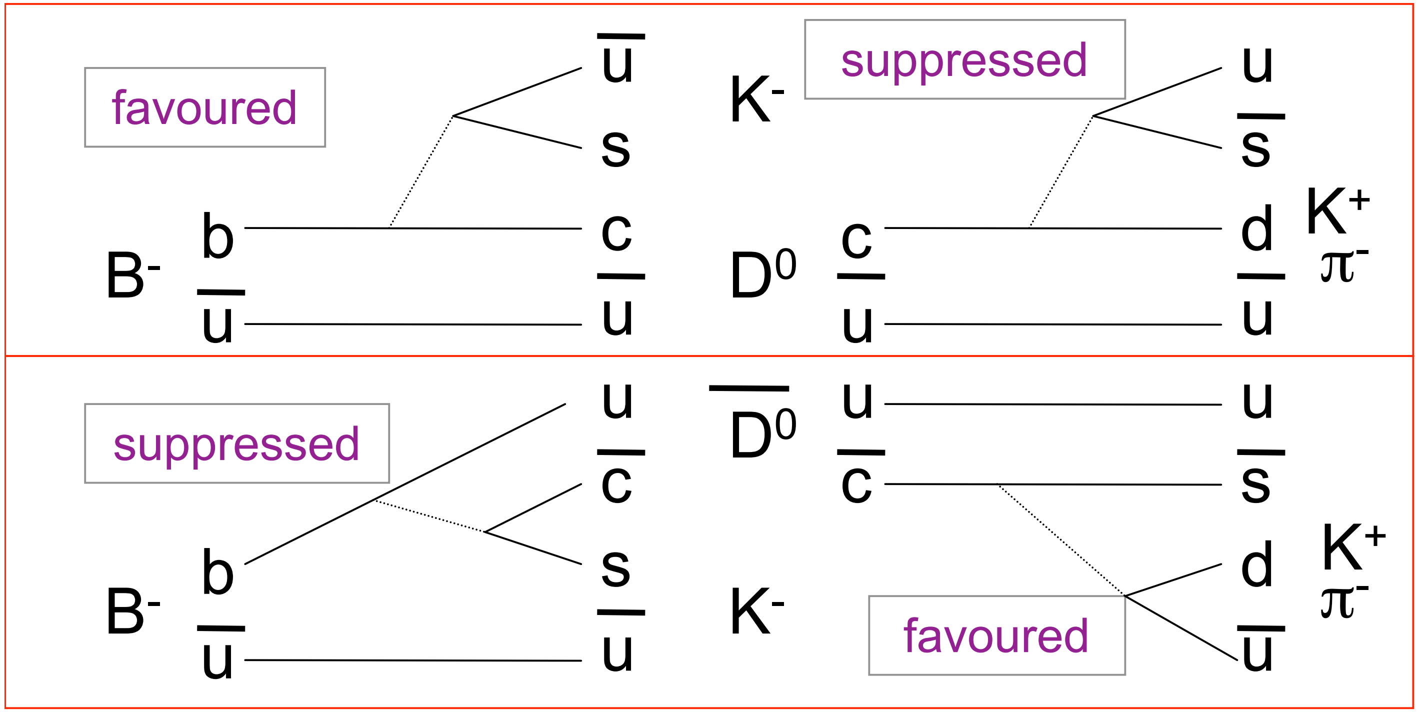
•Very low combinatoric levels.

•Partially reconstructed low mass background shapes determined from MC. Same shape for all modes as the decay is B➔D*X



$B^{\pm} \rightarrow DK^{\pm}$, $D \rightarrow K^{\mp}\pi^{\pm}$ "ADS"

Common final state $K\pi$ favoured & suppressed combination



Comparable overall amplitudes

Large interference
→ Sensitivity to γ

r_D : ratio of suppressed and favoured amplitudes of D decay ~ 0.05

δ_D : strong phase difference in the D decay

Construct observables of ratios of rates. Partial cancellation of systematic uncertainties

$$R_{ADS} = \frac{\Gamma(B^{\pm} \rightarrow [\pi K]_D K^{\pm})}{\Gamma(B^{\pm} \rightarrow [K\pi]_D K^{\pm})}$$

$$R_{ADS} = \frac{r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D)\cos\gamma}{1 + r_B^2 r_D^2 + 2 r_B r_D \cos(\delta_B - \delta_D)\cos\gamma}$$

$B^{\pm} \rightarrow DK^{\pm}$, $D \rightarrow K^{\mp}\pi^{\pm}\pi^{\mp}\pi^{\pm}$ "ADS"

Similar to $D \rightarrow K\pi$

Multibody decay is treated inclusively which leads to introduction of different parameters r_D, δ_D, and $R^{K3\pi}$. Measured at CLEO (PRD 80 031105 (2009))

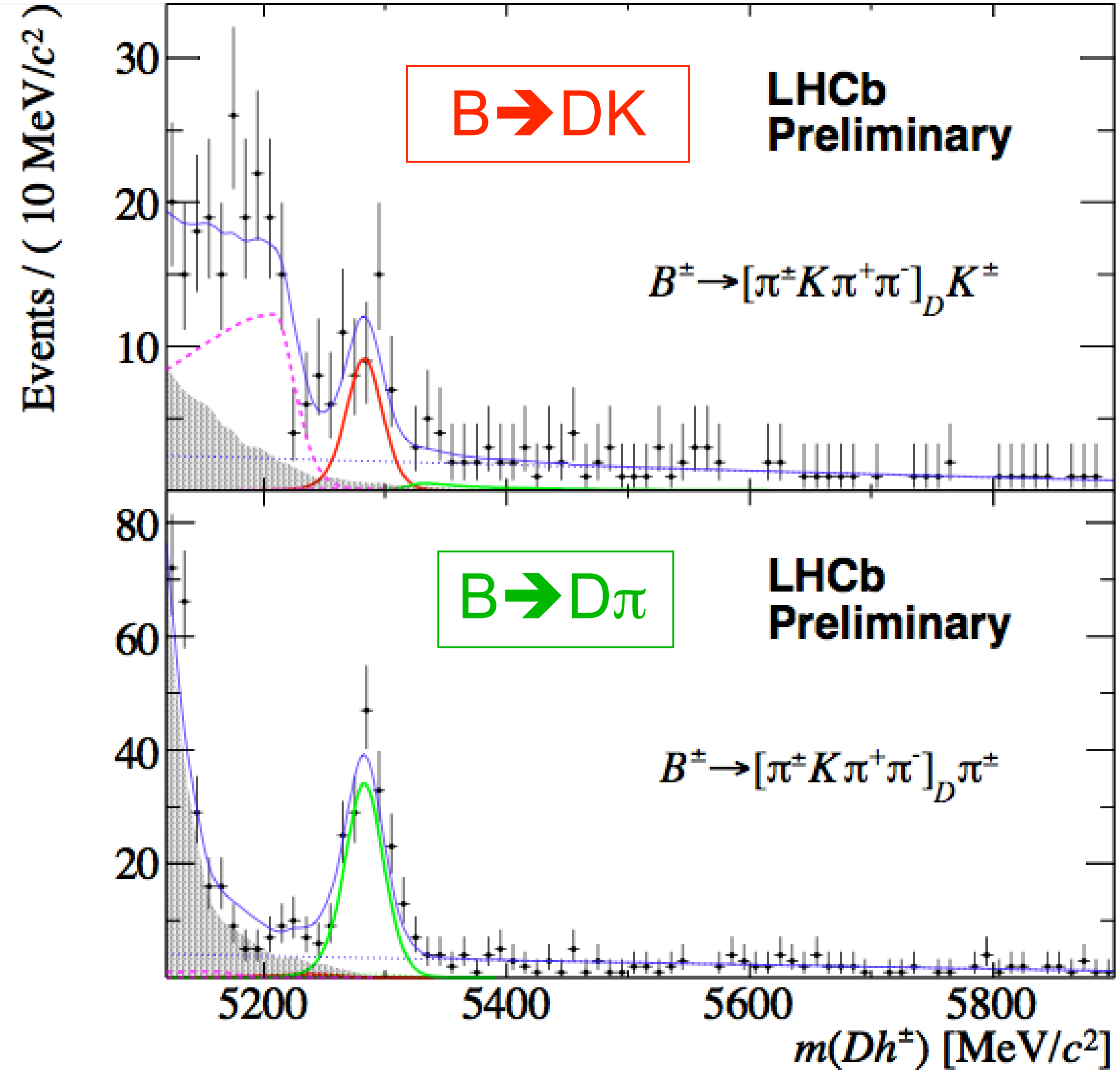
$$R_{ADS}^{K3\pi} = \frac{r_B^2 + {r_D^{K3\pi}}^2 + 2 r_B r_D^{K3\pi} R^{K3\pi} \cos(\delta_B + \delta_D^{K3\pi}) \cos\gamma}{1 + r_B^2 {r_D^{K3\pi}}^2 + 2 r_B r_D^{K3\pi} R^{K3\pi} \cos(\delta_B - \delta_D^{K3\pi}) \cos\gamma}$$

$$A_{ADS}^{K3\pi} = \frac{2 r_B r_D^{K3\pi} R^{K3\pi} \sin(\delta_B + \delta_D^{K3\pi}) \sin\gamma}{R_{ADS}^{K3\pi}}$$

Provides further information than $D \rightarrow K\pi$ alone and has ability to reduce the trigonometric ambiguities when considering just one decay mode

In addition, although CPV is expected to be small in $B \rightarrow D\pi$ similar observables can be measured in this mode for all D modes considered.

Observation of the suppressed decay in $B \rightarrow DK$ & $B \rightarrow D\pi$, $D \rightarrow K\pi\pi\pi$



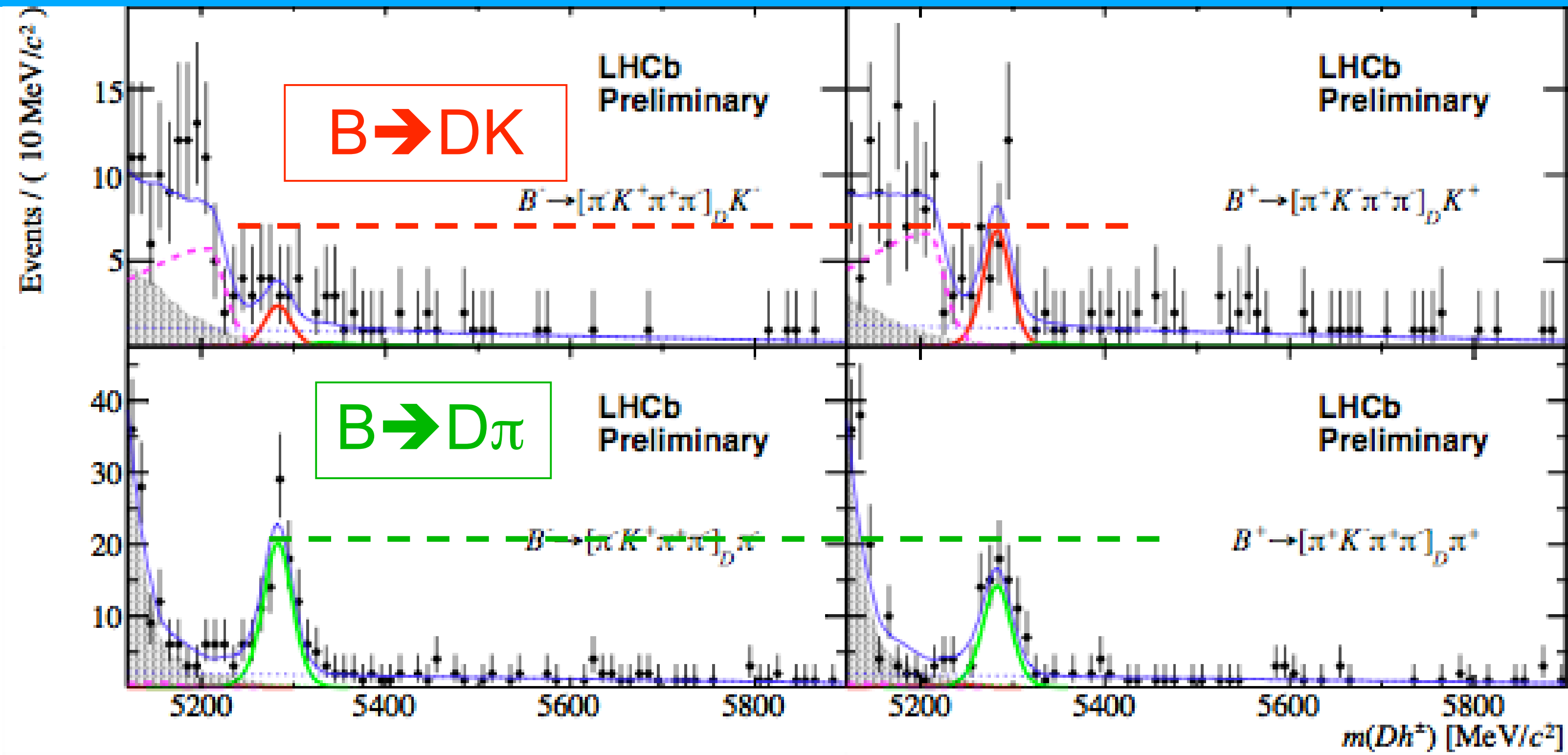
First observation of two rare decays

Signal and background shapes fixed from fit to favoured mode.

$B \rightarrow D\pi$ >10σ

$B \rightarrow DK$ = 5.1σ (incl syst)

Split by charge for CPV



Small systematic uncertainties on yields dominated by:

Particle identification uncertainties for Ratios

Production/interaction/detection effects for Asymmetries

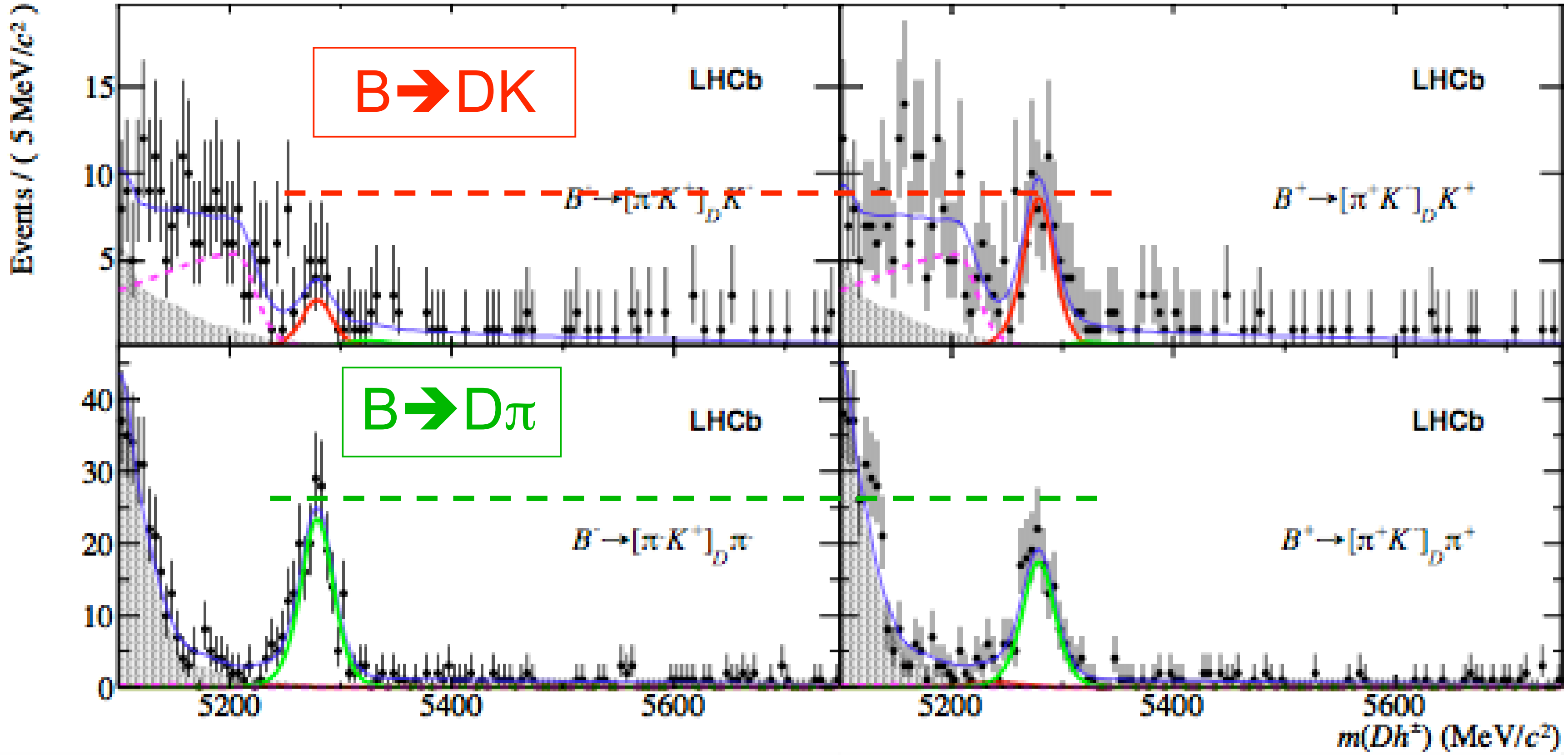
$R_{ADS}(K)$=0.0124±0.0027

$A_{ADS}(K)$=-0.42±0.22

$R_{ADS}(\pi)$=0.00369±0.00036

$A_{ADS}(\pi)$=0.13±0.10

$B^{\pm} \rightarrow [\pi K]_D h^{\pm}$ (ADS modes)

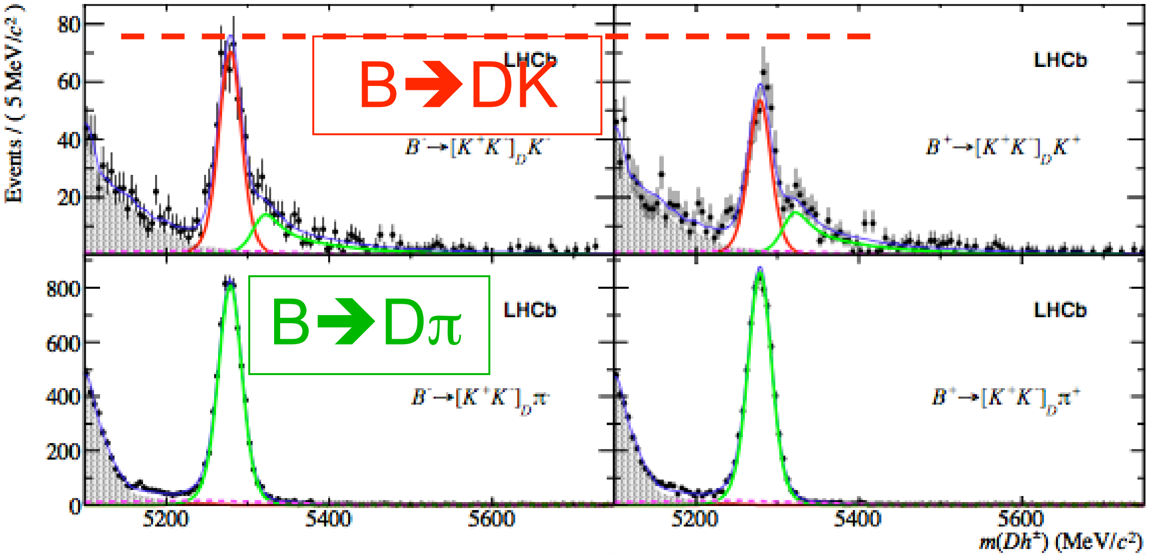


First observation of ADS (opposite side kaons) B→DK [10σ significance]

Asymmetry in B→DK ADS 4.0σ

Hint of asymmetry in B→Dπ ADS 2.4σ

$B^{\pm} \rightarrow [hh]_D h^{\pm}$ "GLW"



Common final state KK or ππ. CP eigenstates

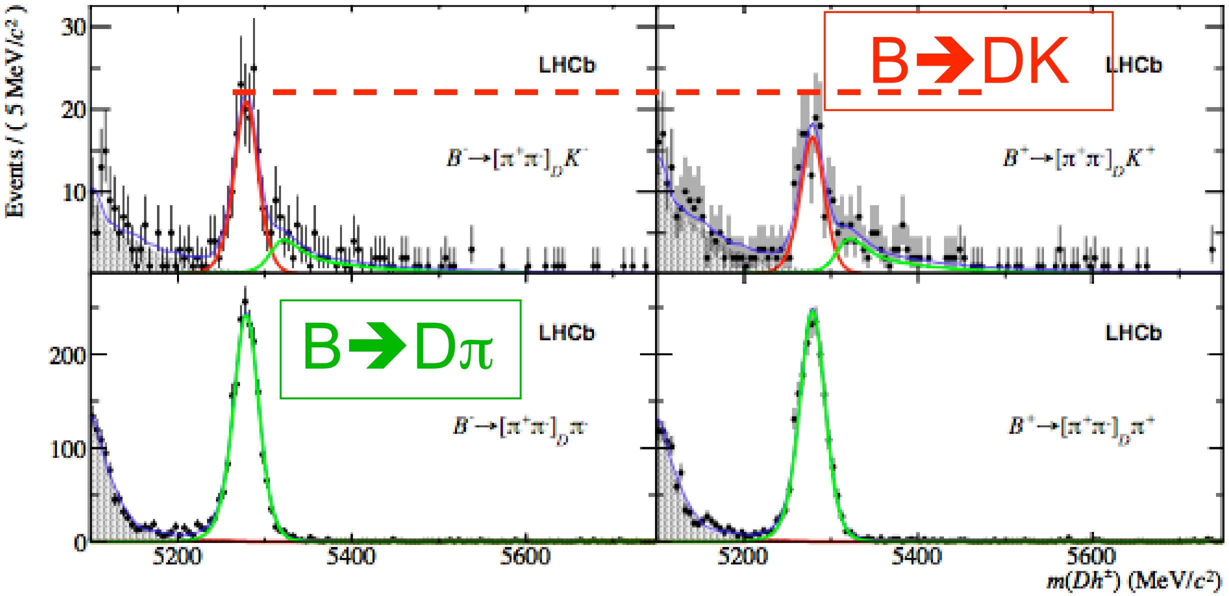
$$A_{CP+} = \frac{\Gamma(B^- \to D_{CP}K^-) - \Gamma(B^+ \to D_{CP}K^+)}{\Gamma(B^- \to D_{CP}K^-) + \Gamma(B^+ \to D_{CP}K^+)}$$

$$A_{CP+} = \frac{2r_B \sin\delta_B \sin\gamma}{1 + r_B^2 + 2r_B \cos\delta_B \cos\gamma}$$

Clear asymmetry in B→DK

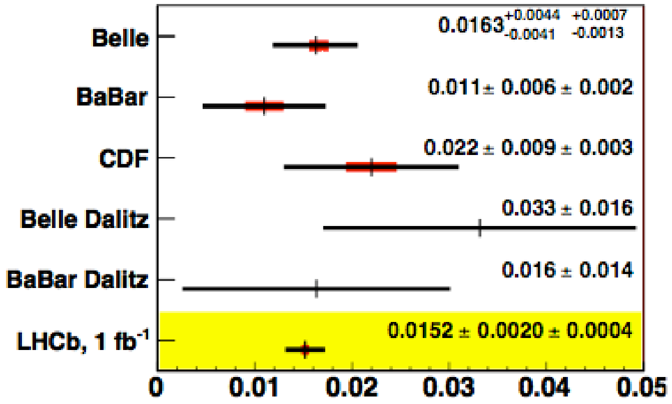
None seen in B→Dπ

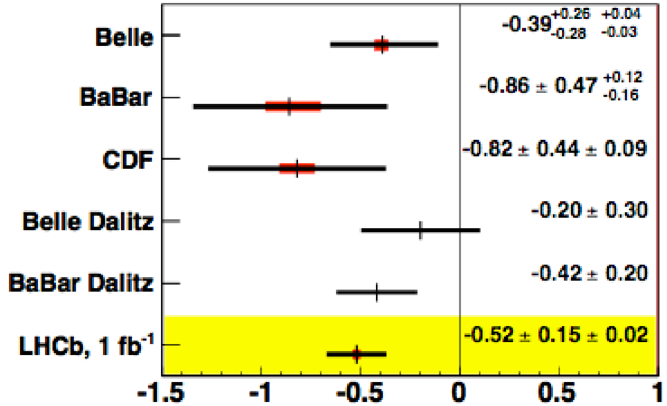
Evidence of non-zero A_{CP+} with 4.5σ significance



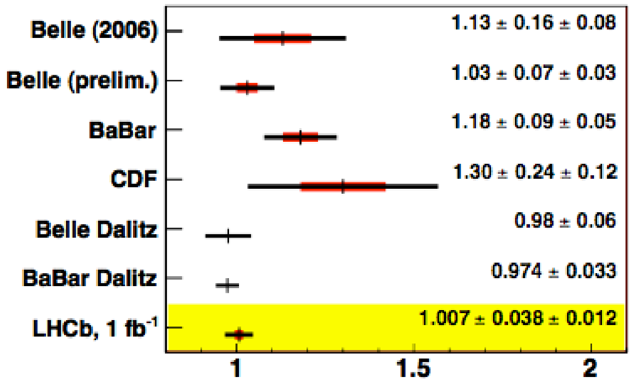
PLB 712 203 (2002)

Results from the two body modes

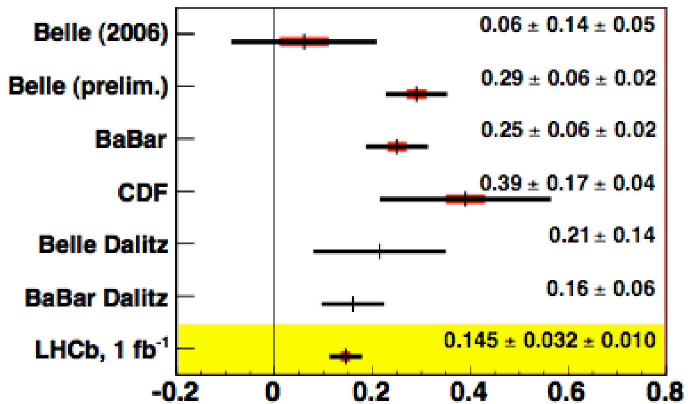




$$R_{ADS} = \frac{r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\gamma}{1 + r_B^2 r_D^2 + 2r_B r_D \cos(\delta_B - \delta_D)\cos\gamma} \quad A_{ADS} = \frac{2r_B r_D \sin(\delta_B + \delta_D)\sin\gamma}{r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\gamma}$$



$$R_{CP+} = 1 + r_B^2 + 2r_B \cos\delta_B \cos\gamma$$

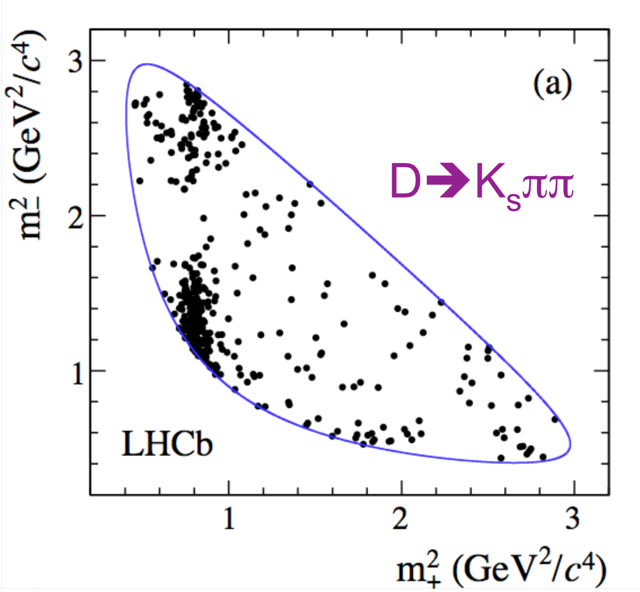


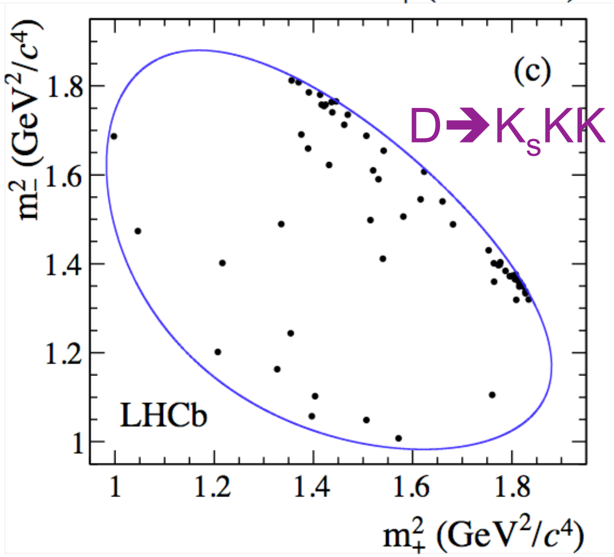
$$A_{CP+} = \frac{2r_B \sin\delta_B \sin\gamma}{1 + r_B^2 + 2r_B \cos\delta_B \cos\gamma}$$

Combining all two body decays, CP violation is observed in B➔DK, D➔hh$^{(')}$ with a significance of 5.8σ

PLB 712 203 (2002)

B→DK, D→$K_s$hh "GGSZ"

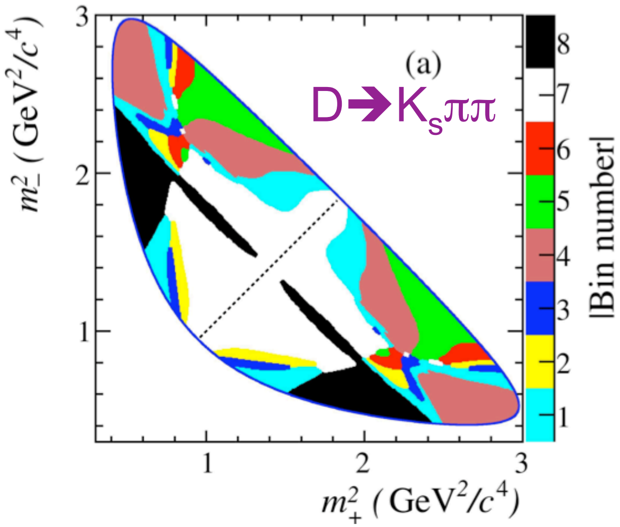


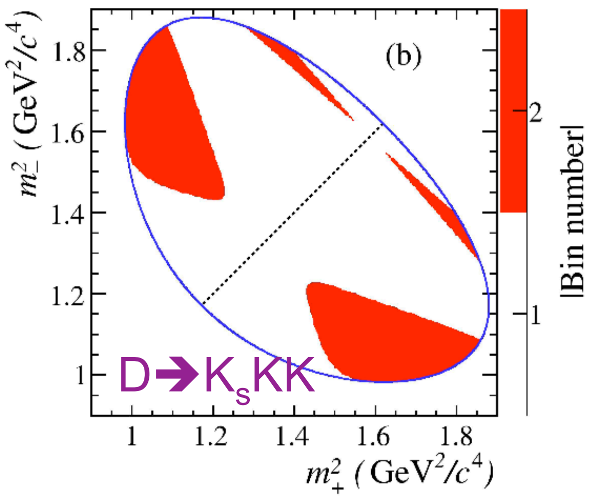


- Both D→$K_s\pi\pi$ and D→K_sKK analysed.
- Analysis not treated as "inclusive". [very little sensitivity]
- Decay analysed on the Dalitz plot.
- Complication: The strong phase difference between D^0 and $\overline{D}^0$ varies over the plot.
- Model-independent approach taken where the strong phase information comes from analysis at CLEO.
- Well defined systematic errors compared to using an amplitude model for D decay

 arXiv: 1209.5869

Principles of measurement





Divide the Dalitz plot into regions, and determine the yield of B^+ & B^- in each.

$$N_{+i}^{+} = n_{B^+}[K_{-i} + (x_+^2 + y_+^2)K_{+i} + 2\sqrt{K_{+i}K_{-i}}(x_+c_{+i} - y_+s_{+i})]$$

$$x_\pm = r_B\cos(\delta_B \pm \gamma), y_\pm = r_B\sin(\delta_B \pm \gamma)$$

K_i - flavour tagged yield in bin i, c_i,s_i - CLEO inputs

Essentially a counting experiment in each bin

Data from D➔K_SKK easily added as two additional bins. x, y parameters are common to both modes.

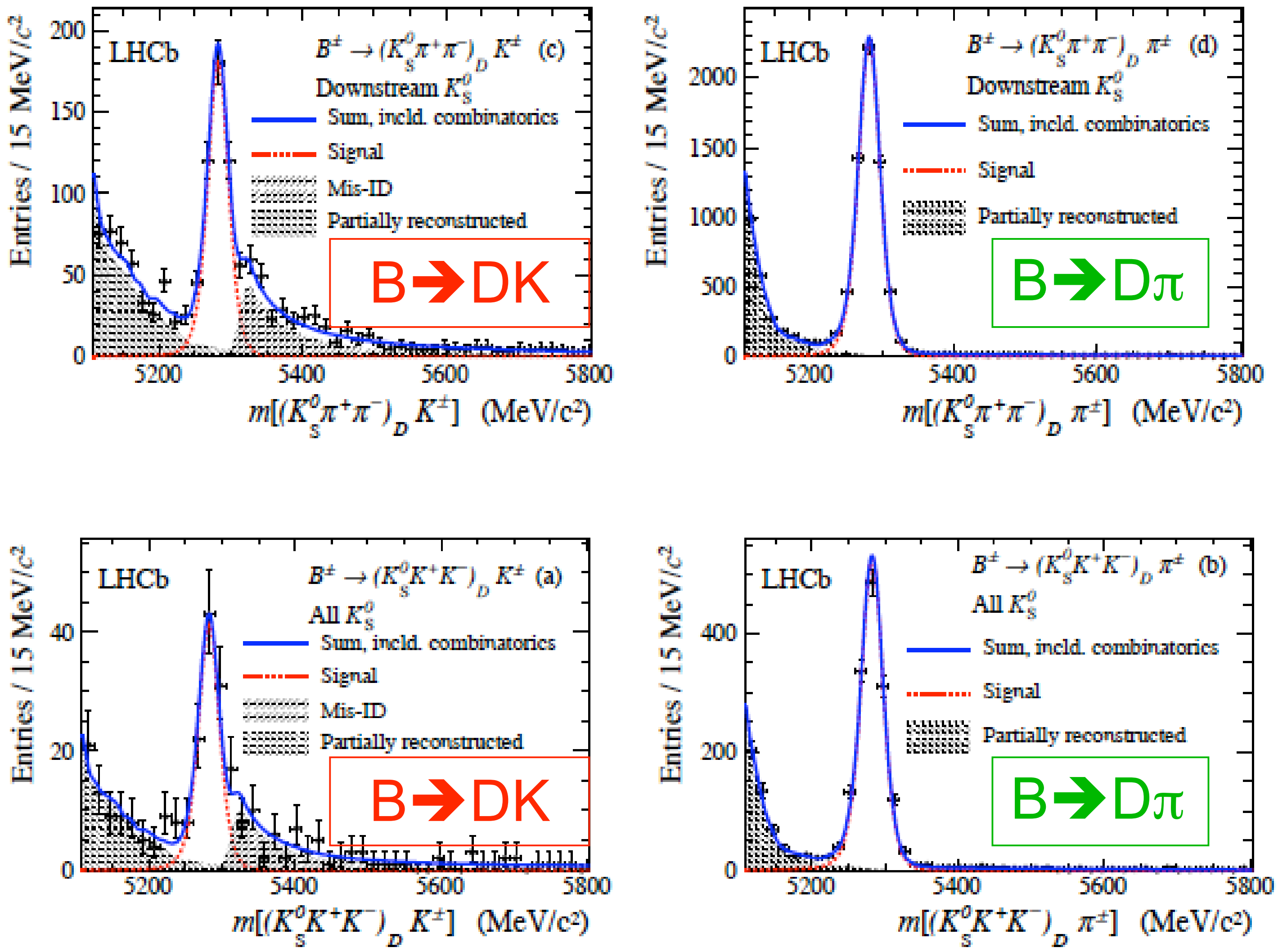
Signal parameterisation

Mass fit determines the parameterisation for the signal and background.

Total yield of B➔DK:

690 D➔$K_s\pi\pi$

110 D➔K_sKK

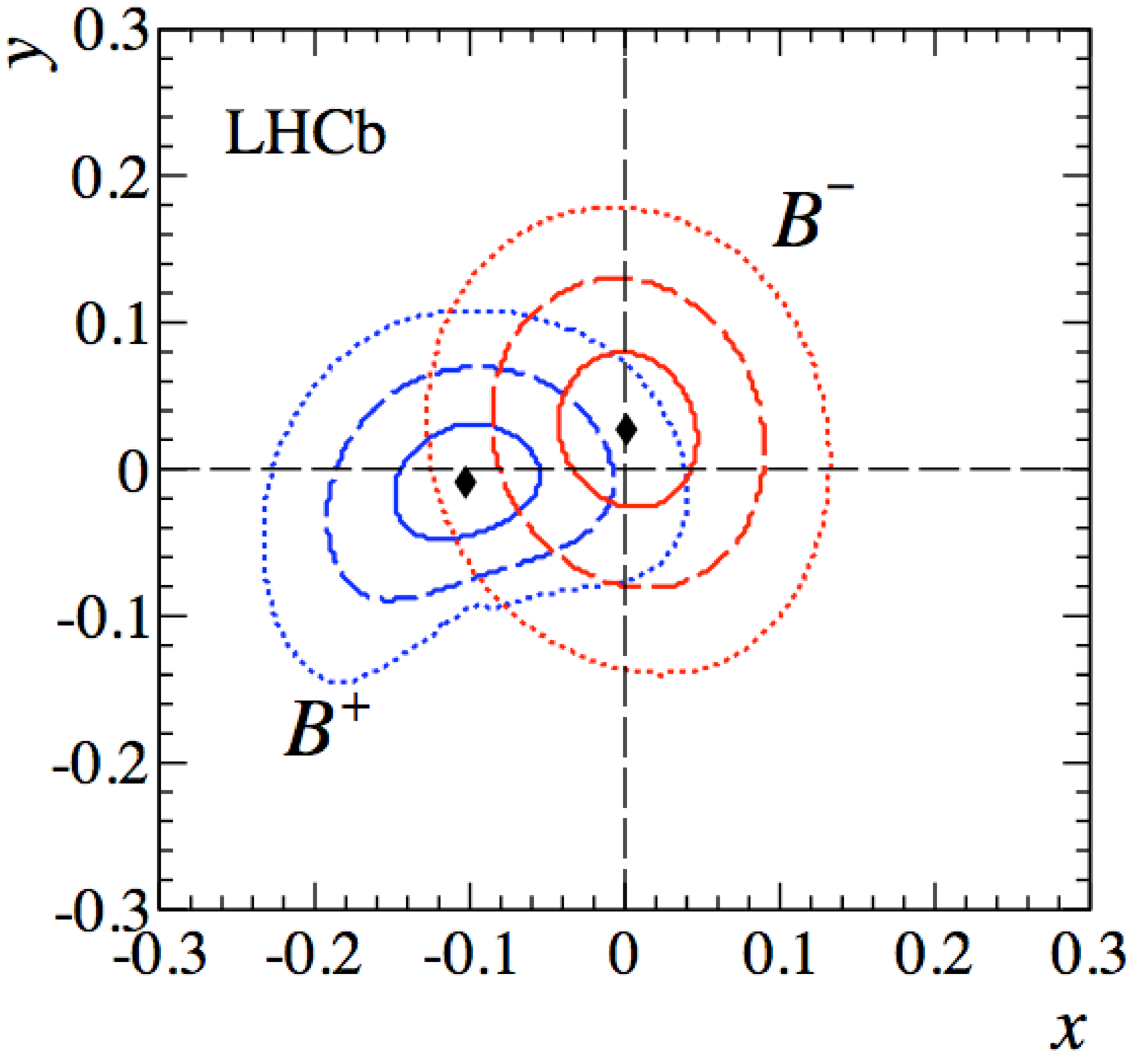


Data then split into bins to determine x,y

arXiv: 1209.5869

Simultaneous binned fit & results on x and y

- Reconstruction efficiency varies over Dalitz plot
- Use Dπ yield in each bin as a control and compare to flavour tagged expectation to derive the efficiency.
- Assumes no CPV - hence no observables determined in Dπ modes.
- Don't determine the yield of DK in each bin separately:
- Simultaneous fit of each bin of $K_s\pi\pi$ and K_sKK data to determine best x and y to fit the distribution of events over the Dalitz plot.
- Likelihood scan of statistical error on x and y shown. Bisector between central points and origin is γ



arXiv: 1209.5869

Results & systematic uncertainties

Uncertainties: statistical, experimental systematics, CLEO inputs.

$$x_- = (0.0 \pm 4.3 \pm 1.5 \pm 0.6) \times 10^{-2}, \; y_- = (2.7 \pm 5.2 \pm 0.8 \pm 2.3) \times 10^{-2},$$

$$x_+ = (-10.3 \pm 4.5 \pm 1.8 \pm 1.4) \times 10^{-2}, \; y_+ = (-0.9 \pm 3.7 \pm 0.8 \pm 3.0) \times 10^{-2},$$

•Results on x, y have similar precision to those from Babar and Belle

•Leading source of experimental systematic uncertainty is the assumption of no CPV in B➔Dπ when determining efficiency.

•Hints from the ADS analysis suggest this may be larger than predicted, hence we have been conservative.

- Not limiting in future as intend to determine efficiency from flavour tagged samples directly in future.

•CLEO input uncertainty expected to reduce with increased B statistics.

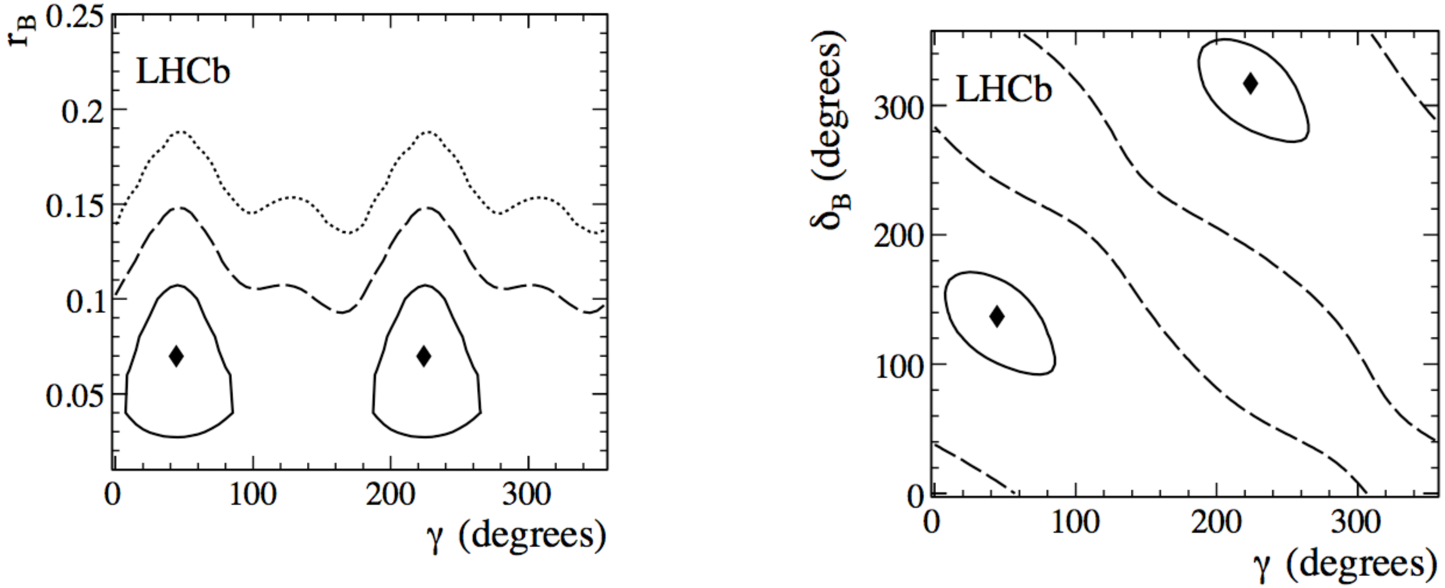
Interpretation on γ

Use a frequentist Feldman-Cousins ordering to determine (stat+syst) confidence intervals for γ, r_B, δ_B set constraints

Results : $$\gamma = 44^{+43°}_{-38}, \delta_B = 137^{+35°}_{-46}, r_B = 0.07 \pm 0.04$$

Two-fold ambiguity remains

Low r_B value increases the uncertainty on γ



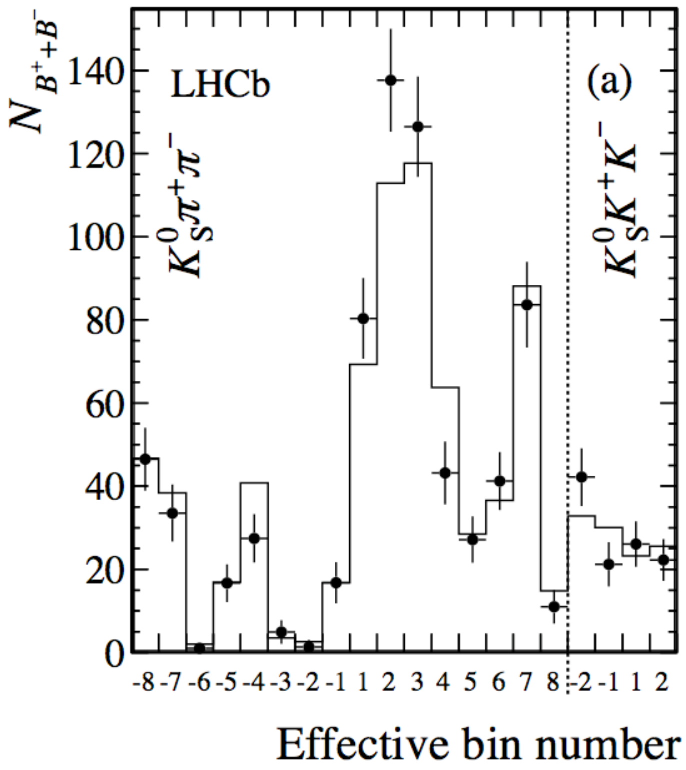
Conclusions

- **First observation** of the suppressed ADS decay in B➔DK and B➔Dπ where D➔Kπππ
- Measurement of observables related to γ in B➔Dh, D➔Kπππ
- Provides new information to add to previous B➔Dh, D➔hh results
- **Model independent analysis of B➔DK, D➔$K_S$hh**
- Can set loose constraints on γ alone with D➔$K_s$hh
- Each observable provides new and different information on the phyiscs parameters of interest.
- **What would be the power of combining all these observables together?**
- **Next talk….**

Backup

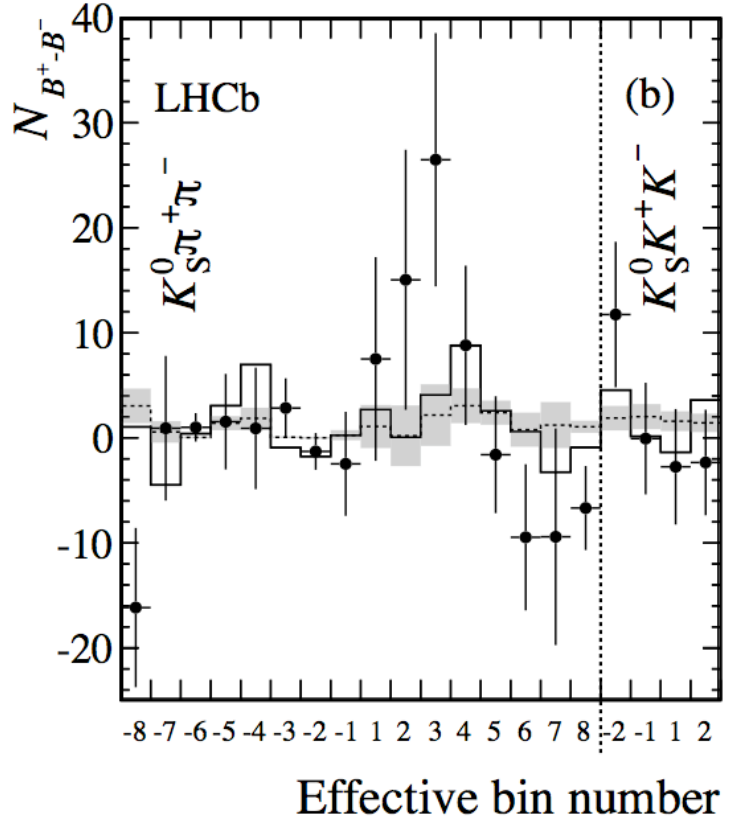
Cross checks on the fit results

Use alternate fit to determine yield of B➔DK in each bin separately & compare to the expectation from the fitted results.



Sum B^+& B^-

Good agreement between fit and prediction



Difference B^+ - B^- ; Grey shading shows no CPV hypothesis (scatter due to statistical uncertainty on efficiency)

B→DK, D→CP eigenstates "GLW"

Both D^0 and $\overline{D^0}$ decay to CP eigenstates KK, ππ [CP even]

$$\frac{\langle B^- \to \overline{D^0} K^- \rangle}{\langle B^- \to D^0 K^- \rangle} = r_B e^{i(\delta_B - \gamma)}$$

r_B ~0.1 Interference ~10%

CP modes

$$R_{CP+} = \frac{\langle \Gamma(B^\pm \to [\pi\pi]_D K^\pm), \Gamma(B^\pm \to [KK]_D K^\pm) \rangle}{\Gamma(B^\pm \to [K\pi]_D K^\pm)} \qquad A_{CP+} = \frac{\Gamma(B^- \to D_{CP}K^-) - \Gamma(B^+ \to D_{CP}K^+)}{\Gamma(B^- \to D_{CP}K^-) + \Gamma(B^+ \to D_{CP}K^+)}$$

favoured mode

$$R_{CP+} = 1 + r_B^2 + 2r_B \cos\delta_B \cos\gamma \qquad A_{CP+} = \frac{2r_B \sin\delta_B \sin\gamma}{1 + r_B^2 + 2r_B \cos\delta_B \cos\gamma}$$