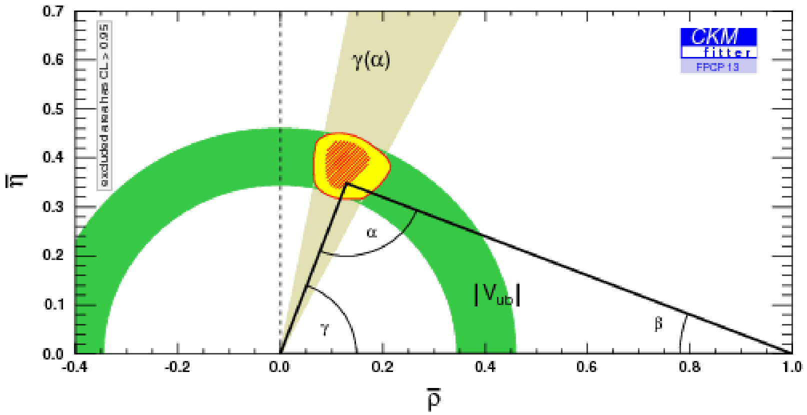
Measurements of $B^{\pm} \rightarrow DK^{\pm}$ decays to constrain the CKM unitarity triangle angle γ and related results at LHCb

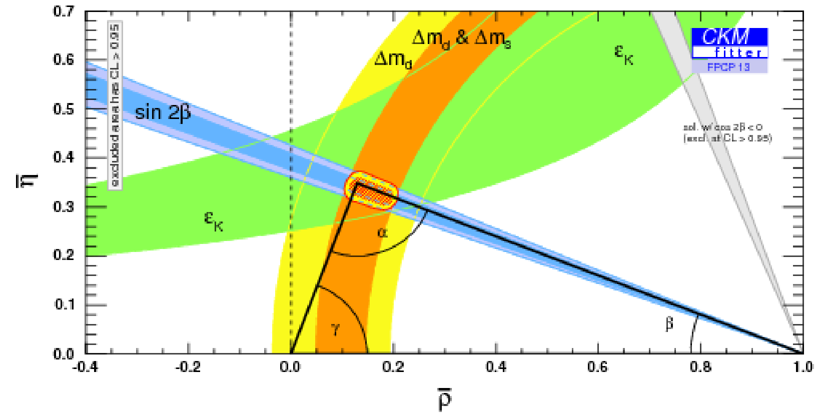
Daniel Craik

on behalf of the LHCb collaboration

15th August 2013

$B^{\pm} \to DK^{\pm}$
Why measure γ from trees?





Constraints on the CKM unitarity triangle due to measurements of (left) tree-level and (right) loop processes. As new physics may enter into loop processes, a disagreement between these two sets of measurements would be a strong sign of new physics.

CKMfitter, FPCP 13

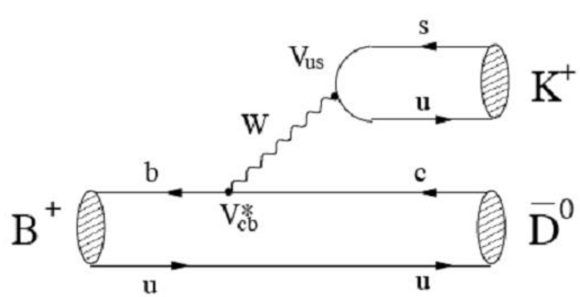
$$\gamma = \left(68.0^{+8.0}_{-8.5}\right)^{\circ}$$

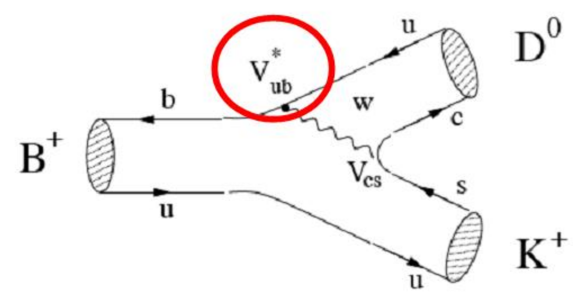
UTfit, Pre-Moriond 13

$$\gamma = (70.8 \pm 7.8)^{\circ}$$

These values already include some of the following results.

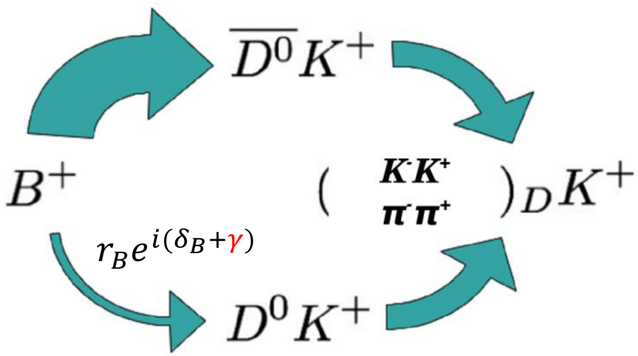
$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}}\right)$$





$B^\pm \to DK^\pm$

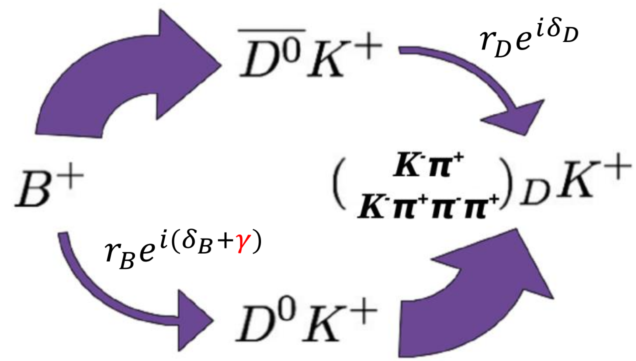
GLW, ADS and GGSZ



Gronau, **L**ondon, **W**yler

Phys. Lett. B 265 (1991) 172

D decays into **CP eigenstates** such as K^+K^- or $\pi^+\pi^-$



Atwood, **D**unietz, **S**oni

Phys. Rev. Lett. 78 (1997) 3257

Suppression in D decay to **quasi-flavour-specific states** reversed to give larger interference

Giri, **G**rossman, **S**offer, **Z**upan

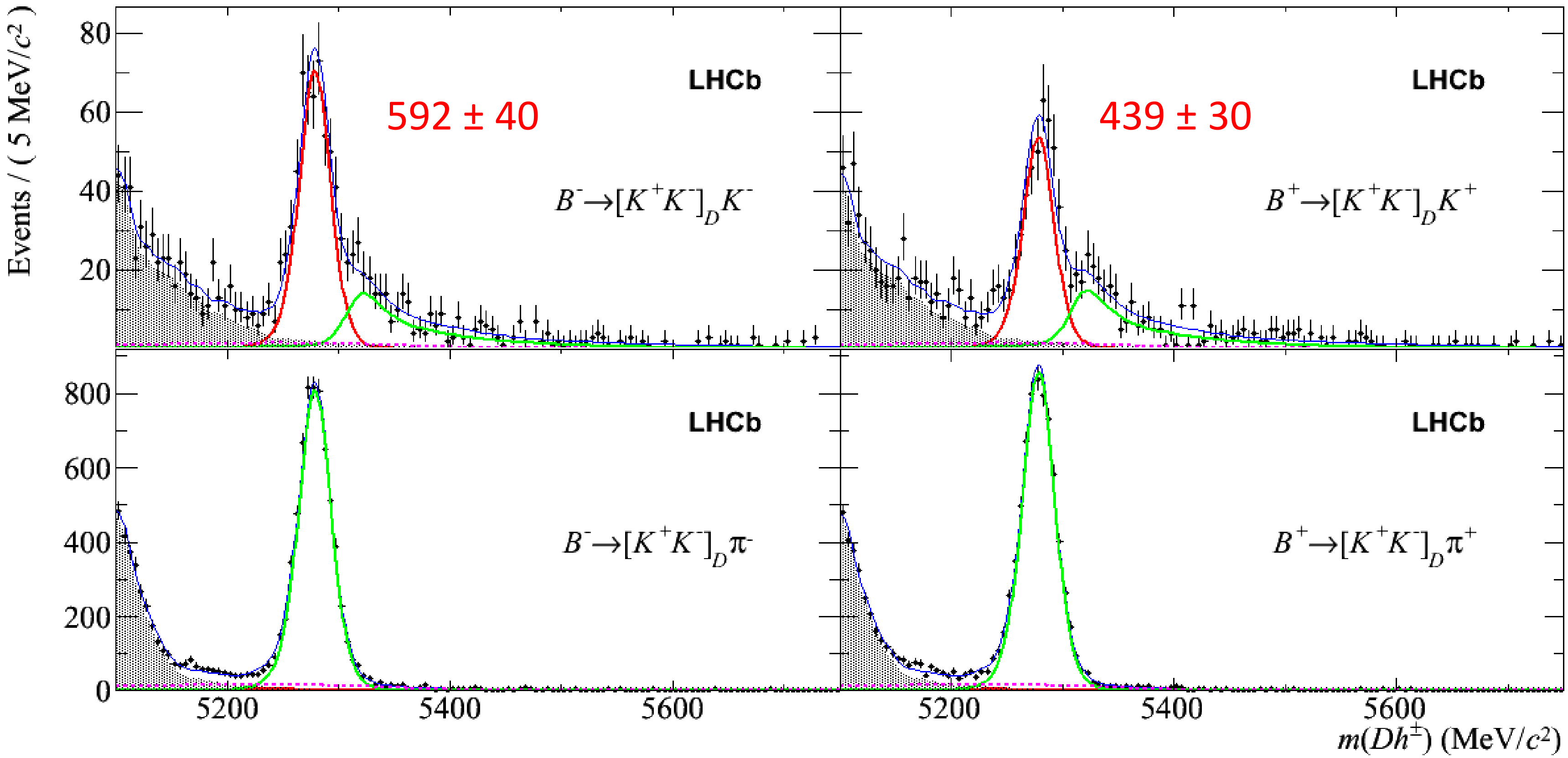
Phys. Rev. D68 (2003) 054018

3-body self-conjugate decays: $D \to K_S^0 h^+h^-$ $(h = \pi, K)$

Exploits interference in the Dalitz plot

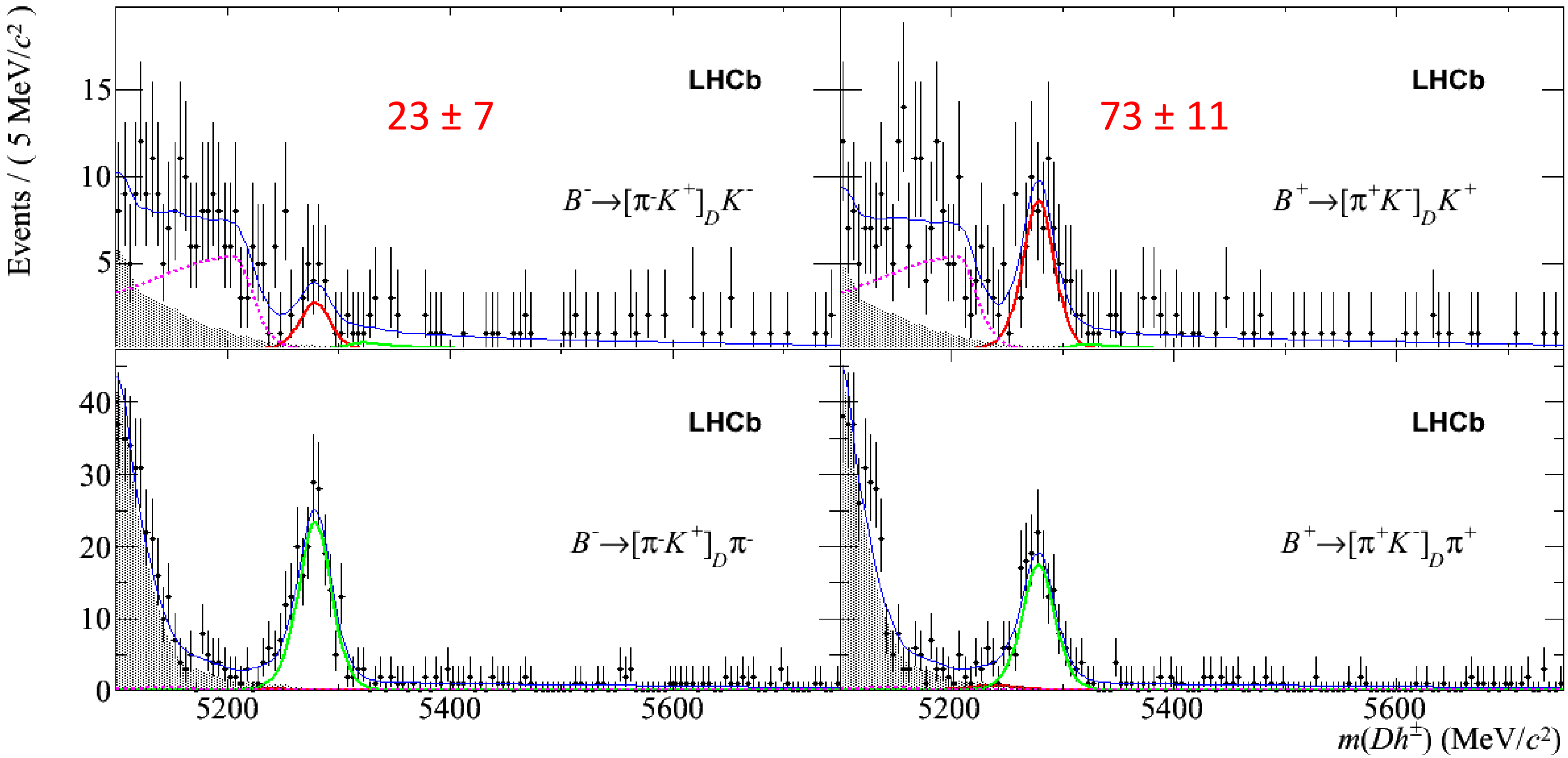
Strong phase, δ_D, varies across the Dalitz plot

2 body GLW ($1 fb^{-1}$)



Phys Lett B 712 (2012), 203-212

2 body ADS ($1fb^{-1}$)



Phys Lett B 712 (2012), 203-212

$B^{\pm} \to Dh^{\pm}$

2 body GLW/ADS observables

3 K/π ratios:

$$R^f_{K/\pi} = \frac{\Gamma(B^- \to D[\to f]K^-) + \Gamma(B^+ \to D[\to \bar{f}]K^+)}{\Gamma(B^- \to D[\to f]\pi^-) + \Gamma(B^+ \to D[\to \bar{f}]\pi^+)} = \begin{cases} R_{\text{cab}} \dfrac{1 + \left(r_B^K r_f\right)^2 + 2 r_B^K r_f \cos\left(\delta_B^K - \delta_f\right)\cos\gamma + M_-^K + M_+^K}{1 + \left(r_B^\pi r_f\right)^2 + 2 r_B^\pi r_f \cos\left(\delta_B^\pi - \delta_f\right)\cos\gamma + M_-^\pi + M_+^\pi}, & f = K\pi \\ R_{\text{cab}} \dfrac{1 + (r_B^K)^2 + 2 r_B^K \cos\delta_B^K \cos\gamma}{1 + (r_B^\pi)^2 + 2 r_B^\pi \cos\delta_B^\pi \cos\gamma}, & f = \pi\pi, KK \end{cases}$$

6 charge asymmetries:

$$A^f_h = \frac{\Gamma(B^- \to D[\to f]h^-) - \Gamma(B^+ \to D[\to \bar{f}]h^+)}{\Gamma(B^- \to D[\to f]h^-) + \Gamma(B^+ \to D[\to \bar{f}]h^+)} = \begin{cases} \dfrac{2 r_B^h r_f \sin\left(\delta_B^h - \delta_f\right)\sin\gamma + M_-^h - M_+^h}{1 + \left(r_B^h r_f\right)^2 + 2 r_B^h r_f \cos\left(\delta_B^h - \delta_f\right)\cos\gamma + M_-^h + M_+^h}, & f = K\pi \\ \dfrac{2 r_B^h \sin\delta_B^h \sin\gamma}{1 + \left(r_B^h\right)^2 + 2 r_B^h \cos\delta_B^h \cos\gamma} + A_{CP}^{D\to f}, & f = \pi\pi, KK \end{cases}$$

4 Kπ suppressed mode ratios:

$$R_h^{\pm} = \frac{(B^\pm \to D[f_{\text{sup}}]h^\pm)}{(B^\pm \to D[f]h^\pm)} = \frac{r_f^2 + \left(r_B^h\right)^2 + 2 r_B^h r_f \cos\left(\delta_B^h - \delta_f \pm \gamma\right) - \left[M_\pm^h\right]_{\text{sup}}}{1 + \left(r_B^h r_f\right)^2 + 2 r_B^h r_f \cos\left(\delta_B^h - \delta_f \pm \gamma\right)\cos\gamma + M_\pm^h}, \quad f = K^+\pi^-, f_{\text{sup}} = \pi^+ K^-$$

13 observables

$B^\pm \to Dh^\pm$

2 body GLW/ADS observables

3 K/π ratios:

$$R^f_{K/\pi} = \frac{\Gamma(B^- \to D[\to f]K^-) + \Gamma(B^+ \to D[\to \bar{f}]K^+)}{\Gamma(B^- \to D[\to f]\pi^-) + \Gamma(B^+ \to D[\to \bar{f}]\pi^+)} = \begin{cases} R_{\text{cab}} \dfrac{1 + (r_B^K r_f)^2 + 2r_B^K r_f \cos(\delta_B^K - \delta_f)\cos\gamma + M_-^K + M_+^K}{1 + (r_B^\pi r_f)^2 + 2r_B^\pi r_f \cos(\delta_B^\pi - \delta_f)\cos\gamma + M_-^\pi + M_+^\pi}, & f = K\pi \\ R_{\text{cab}} \dfrac{1 + (r_B^K)^2 + 2r_B^K \cos\delta_B^K \cos\gamma}{1 + (r_B^\pi)^2 + 2r_B^\pi \cos\delta_B^\pi \cos\gamma}, & f = \pi\pi, KK \end{cases}$$

6 charge asymmetries:

$$A_h^f = \frac{\Gamma(B^- \to D[\to f]h^-) - \Gamma(B^+ \to D[\to \bar{f}]h^+)}{\Gamma(B^- \to D[\to f]h^-) + \Gamma(B^+ \to D[\to \bar{f}]h^+)} = \begin{cases} \dfrac{2r_B^h r_f \sin(\delta_B^h - \delta_f)\sin\gamma + M_-^h - M_+^h}{1 + (r_B^h r_f)^2 + 2r_B^h r_f \cos(\delta_B^h - \delta_f)\cos\gamma + M_-^h + M_+^h}, & f = K\pi \\ \dfrac{2r_B^h \sin\delta_B^h \sin\gamma}{1 + (r_B^h)^2 + 2r_B^h \cos\delta_B^h \cos\gamma} + A_{CP}^{D\to f}, & f = \pi\pi, KK \end{cases}$$

D^0 mixing terms included – important for $B^\pm \to D\pi^\pm$

4 Kπ suppressed mode ratios:

$$R_h^\pm = \frac{(B^\pm \to D[f_{\text{sup}}]h^\pm)}{(B^\pm \to D[f]h^\pm)} = \frac{r_f^2 + (r_B^h)^2 + 2r_B^h r_f \cos(\delta_B^h - \delta_f \pm \gamma) - [M_\pm^h]_{\text{sup}}}{1 + (r_B^h r_f)^2 + 2r_B^h r_f \cos(\delta_B^h - \delta_f \pm \gamma)\cos\gamma + M_\pm^h}, \quad f = K^+\pi^-, f_{\text{sup}} = \pi^+K^-$$

13 observables

$$M_\pm^h = \left(\kappa_f r_f \left((r_B^h)^2 - 1\right)\sin\delta_f + r_B^h(1 - r_f^2)\sin(\delta_B^h \pm \gamma)\right) a_D x_D - \left(\kappa_f r_f \left((r_B^h)^2 + 1\right)\cos\delta_f + r_B^h(1 + r_f^2)\cos(\delta_B^h \pm \gamma)\right) a_D y_D$$

$$[M_\pm^h]_{\text{sup}} = \left(\kappa_f r_f \left((r_B^h)^2 - 1\right)\sin\delta_f + r_B^h(1 - r_f^2)\sin(\delta_B^h \pm \gamma)\right) a_D x_D + \left(\kappa_f r_f \left((r_B^h)^2 + 1\right)\cos\delta_f + r_B^h(1 + r_f^2)\cos(\delta_B^h \pm \gamma)\right) a_D y_D$$

$B^{\pm} \to Dh^{\pm}$

4 body (K3π) ADS observables

1 K/π ratio:

$$R^f_{K/\pi} = \frac{\Gamma(B^- \to D[\to f]K^-) + \Gamma(B^+ \to D[\to \bar{f}]K^+)}{\Gamma(B^- \to D[\to f]\pi^-) + \Gamma(B^+ \to D[\to \bar{f}]\pi^+)} = R_{\text{cab}} \frac{1 + (r_B^K r_f)^2 + 2 r_B^K r_f \kappa_f \cos(\delta_B^K - \delta_f) \cos\gamma + M_-^K + M_+^K}{1 + (r_B^\pi r_f)^2 + 2 r_B^\pi r_f \kappa_f \cos(\delta_B^\pi - \delta_f) \cos\gamma + M_-^\pi + M_+^\pi}$$

2 charge asymmetries:

$$A_h^f = \frac{\Gamma(B^- \to D[\to f]h^-) - \Gamma(B^+ \to D[\to \bar{f}]h^+)}{\Gamma(B^- \to D[\to f]h^-) + \Gamma(B^+ \to D[\to \bar{f}]h^+)} = \frac{2 r_B^h r_f \kappa_f \sin(\delta_B^h - \delta_f) \sin\gamma + M_-^h - M_+^h}{1 + (r_B^h r_f)^2 + 2 r_B^K r_f \kappa_f \cos(\delta_B^h - \delta_f) \cos\gamma + M_-^h + M_+^h}$$

4 Kπππ suppressed mode ratios:

$$R_h^{\pm} = \frac{(B^{\pm} \to D[f_{\text{sup}}]h^{\pm})}{(B^{\pm} \to D[f]h^{\pm})} = \frac{r_f^2 + (r_B^h)^2 + 2 r_B^h r_f \kappa_f \cos(\delta_B^h - \delta_f \pm \gamma) - [M_{\pm}^h]_{\text{sup}}}{1 + (r_B^h r_f)^2 + 2 r_B^h r_f \kappa_f \cos(\delta_B^h - \delta_f \pm \gamma) \cos\gamma + M_{\pm}^h}$$

7 observables

$$M_{\pm}^h = \left(\kappa_f r_f \left((r_B^h)^2 - 1\right) \sin\delta_f + r_B^h (1 - r_f^2) \sin(\delta_B^h \pm \gamma)\right) a_D x_D - \left(\kappa_f r_f \left((r_B^h)^2 + 1\right) \cos\delta_f + r_B^h (1 + r_f^2) \cos(\delta_B^h \pm \gamma)\right) a_D y_D$$

$$[M_{\pm}^h]_{\text{sup}} = \left(\kappa_f r_f \left((r_B^h)^2 - 1\right) \sin\delta_f + r_B^h (1 - r_f^2) \sin(\delta_B^h \pm \gamma)\right) a_D x_D + \left(\kappa_f r_f \left((r_B^h)^2 + 1\right) \cos\delta_f + r_B^h (1 + r_f^2) \cos(\delta_B^h \pm \gamma)\right) a_D y_D$$

$B^\pm \to Dh^\pm$

GGSZ observables

Parameters extracted from a fit to the Dalitz plot where the population of each bin is given by:

$$N^+_{\pm i} = h_{B^+}\left[K_{\mp i} + (x_+^2 + y_+^2)K_{\pm i} + 2\sqrt{K_i K_{-i}}(x_+ c_{\pm i} \mp y_+ s_{\pm i})\right]$$
$$N^-_{\pm i} = h_{B^-}\left[K_{\pm i} + (x_-^2 + y_-^2)K_{\mp i} + 2\sqrt{K_i K_{-i}}(x_- c_{\pm i} \pm y_- s_{\pm i})\right]$$

$K_{\pm i}$ is the efficiency corrected yield in bin $\pm i$ due to D^0 flavour tagged candidates from BaBar.

Phys. Rev. D 78, 034023 (2008), Phys. Rev. Lett. 105, 121801 (2010)

$c_{\pm i}$ and $s_{\pm i}$ are the cosine and sine of the strong phase, δ_D, in bin $\pm i$ from CLEO-c.

Phys. Rev. D 82, 112006 (2010)

Binned fit – model independent

4 observables ($N^\pm_{\pm i}$) per pair of bins

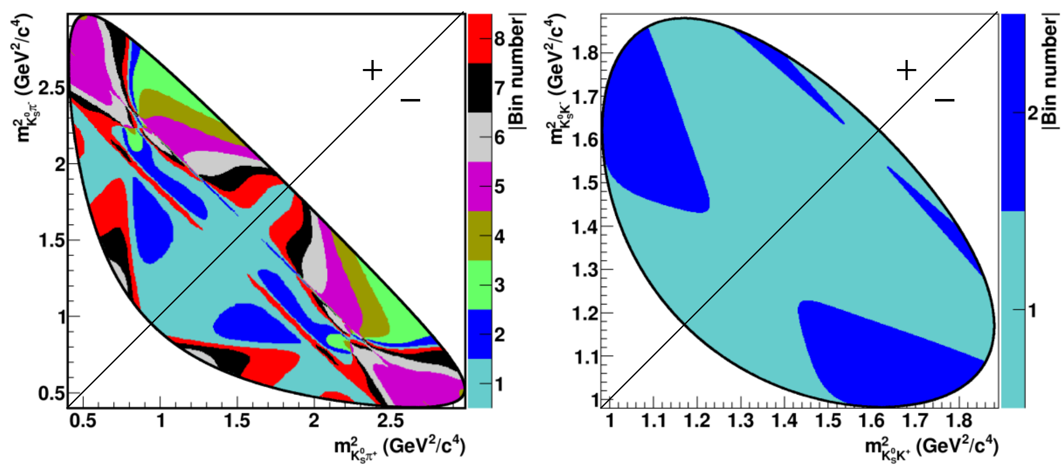
4 Cartesian parameters:

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

2 normalisation factors

$$h_{B^\pm}$$

4 Cartesian parameters used for γ



Bins chosen for (left) $D \to K^0_S\pi^+\pi^-$ and (right) $\mathrm{D} \to K^0_S K^+ K^-$ to maximise statistical sensitivity

$B^{\pm} \to Dh^{\pm}$ γ combination (1fb^{-1})

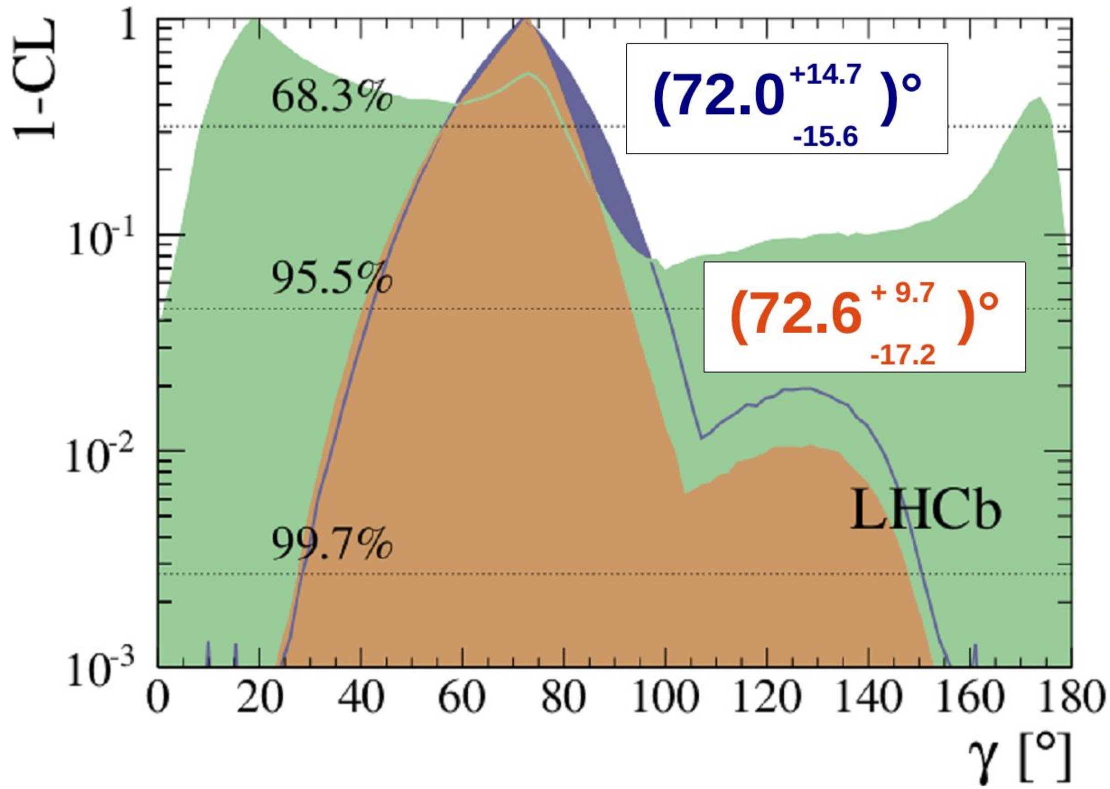
- Combine observables from different analyses using a frequentist approach
- More precise than averaging because different measurements are more sensitive to different parameters
- Assume almost Gaussian observables and Gaussian systematic uncertainties
- Include external constraints

Analysis	N_{obs}	Parameters
$B^{\pm} \to Dh^{\pm}, D \to hh$ GLW/ADS (1fb^{-1})	13	$\gamma, r_B^K, \delta_B^K, r_B^\pi, \delta_B^\pi, R_{\text{cab}}, r_{K\pi}, \delta_{K\pi}, A_{CP}^{D\to\pi\pi}, A_{CP}^{D\to KK}, x_D, y_D$
$B^{\pm} \to Dh^{\pm}, D \to K_s^0 hh$ GGSZ (1fb^{-1})	4	$\gamma, r_B^K, \delta_B^K$
$B^{\pm} \to Dh^{\pm}, D \to K3\pi$ ADS (1fb^{-1})	7	$\gamma, r_B^K, \delta_B^K, r_B^\pi, \delta_B^\pi, R_{\text{cab}}, r_{K3\pi}, \delta_{K3\pi}, \kappa_{K3\pi}, x_D, y_D$
CLEO $D^0 \to K\pi, D^0 \to K3\pi$	9	$x_D, y_D, \delta_{K\pi}, \delta_{K3\pi}, \kappa_{K3\pi}, r_{K\pi}, r_{K3\pi}, \mathcal{B}(K\pi), \mathcal{B}(K3\pi)$
HFAG charm system CP violation	2	$A_{CP}^{D\to\pi\pi}, A_{CP}^{D\to KK}$
LHCb charm mixing	3	$x_D, y_D, \delta_{K\pi}, r_{K\pi}$

$B^{\pm} \rightarrow Dh^{\pm}$ γ combination (1fb^{-1})

- First γ measurement to account for D^0 mixing
- First combination to include $B^{\pm} \rightarrow D\pi^{\pm}$
- Good agreement with B factory results
- Uncertainties comparable to B factory results

arXiv:1305:2050



DK (purple)
Dπ (green)
DK & Dπ (orange)

BaBar
$\gamma = (69^{+17}_{-16})°$

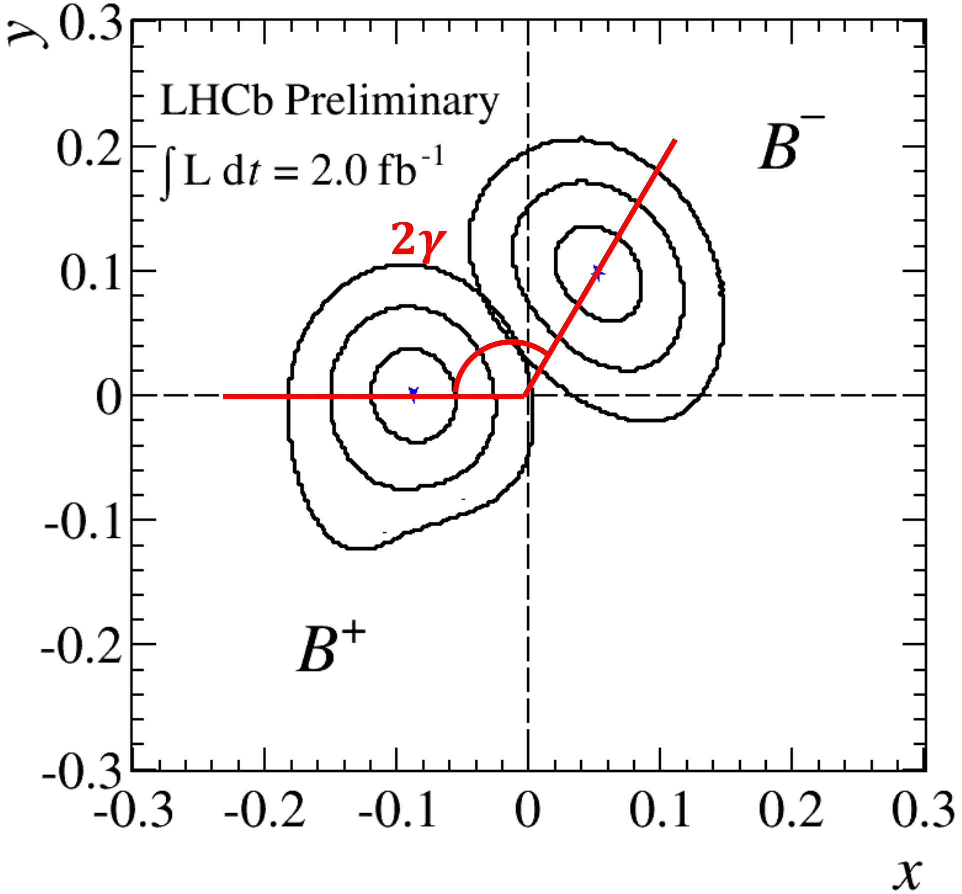
Phys. Rev. D 87, 052015 (2013)

Belle
$\gamma = (68^{+15}_{-14})°$

arXiv:1301.2033

$B^{\pm} \rightarrow DK^{\pm}$

GGSZ update: 2fb^{-1}



$$x_+ = (-8.7 \pm 3.1 \pm 1.6 \pm 0.6) \times 10^{-2}$$
$$x_- = (5.3 \pm 3.2 \pm 0.9 \pm 0.9) \times 10^{-2}$$
$$y_+ = (0.1 \pm 3.6 \pm 1.4 \pm 1.9) \times 10^{-2}$$
$$y_- = (9.9 \pm 3.6 \pm 2.2 \pm 1.6) \times 10^{-2}$$

where the uncertainties are statistical, systematic and due to the strong phase measurements used in the fit respectively.

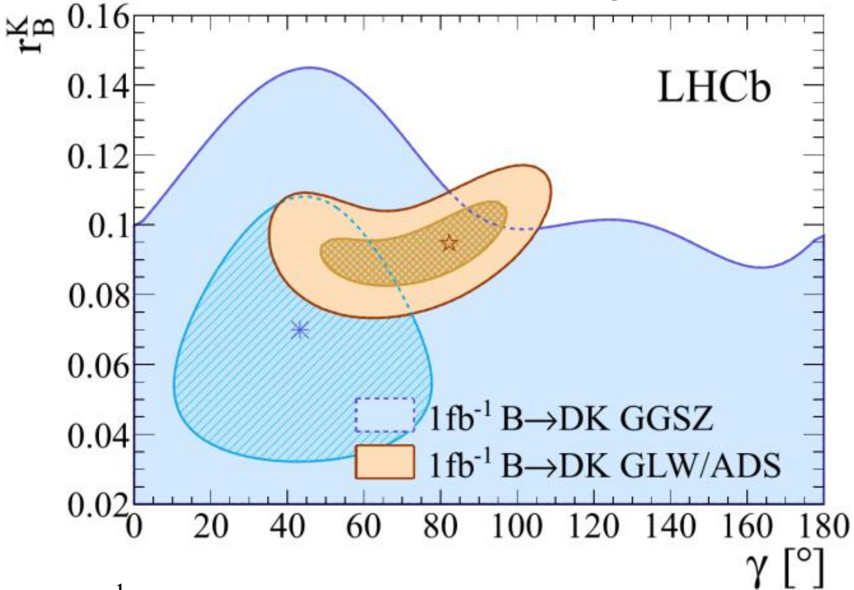
$$\gamma = (57 \pm 16)^\circ$$

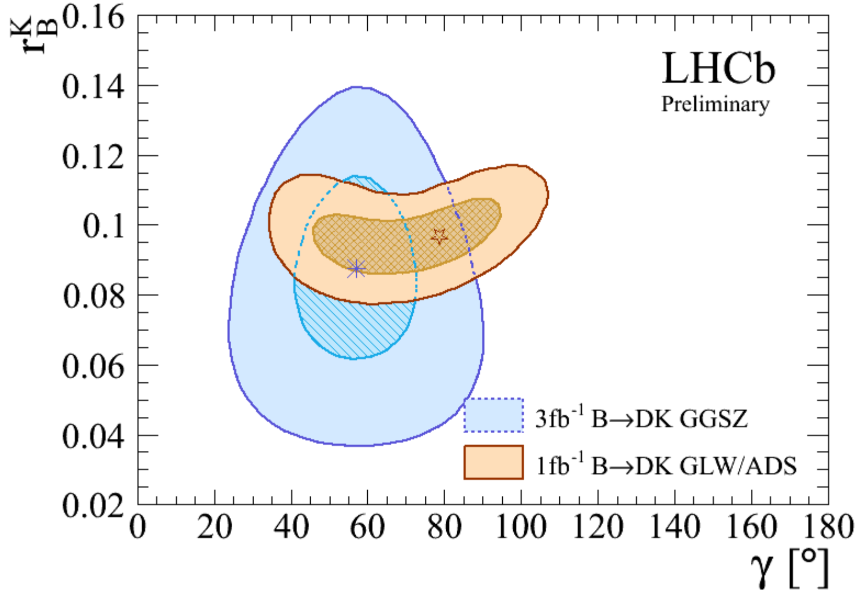
$$r_B = (8.8^{+2.3}_{-2.4}) \times 10^{-2}$$

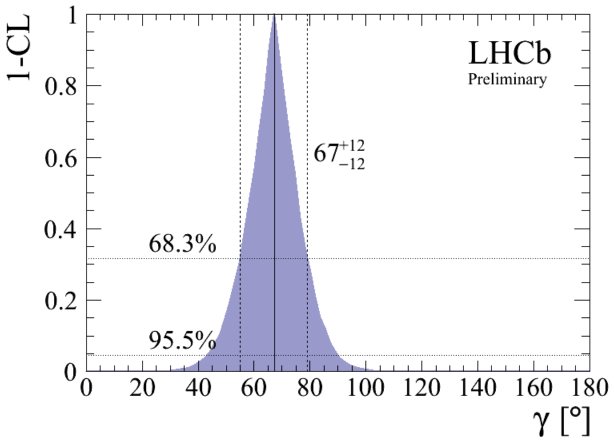
$$\delta_B = \left(124^{+15}_{-17}\right)^\circ$$

LHCb-CONF-2013-004

$B^{\pm} \to DK^{\pm}$ GGSZ update: $1\text{fb}^{-1} \to 3\text{fb}^{-1}$







- First LHCb γ analysis to benefit from 2012 data
- Results significantly improved
- Best γ measurement from a single experiment
- Other 3fb^{-1} analyses to follow

$$\gamma = (67 \pm 12)^{\circ}$$

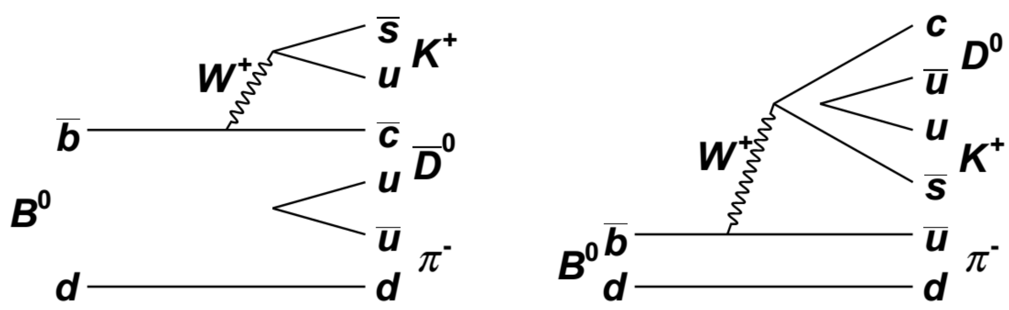
LHCb-CONF-2013-006

$B^0_{(s)} \to DK\pi$

- $B^0 \to DK^+\pi^-$ has potential for a future measurement of γ
  - Interference of $b \to c$ and $b \to u$ amplitudes of a similar magnitude
  - LHCb has already made measurements of $\mathrm{B}^0 \to \mathrm{DK}^{*0}$ (GLW on $1\mathrm{fb}^{-1}$ of data) *JHEP 1302 (2013) 067*
  - Dalitz plot analysis of $B^0 \to DK^+\pi^-$ will offer increased sensitivity to γ

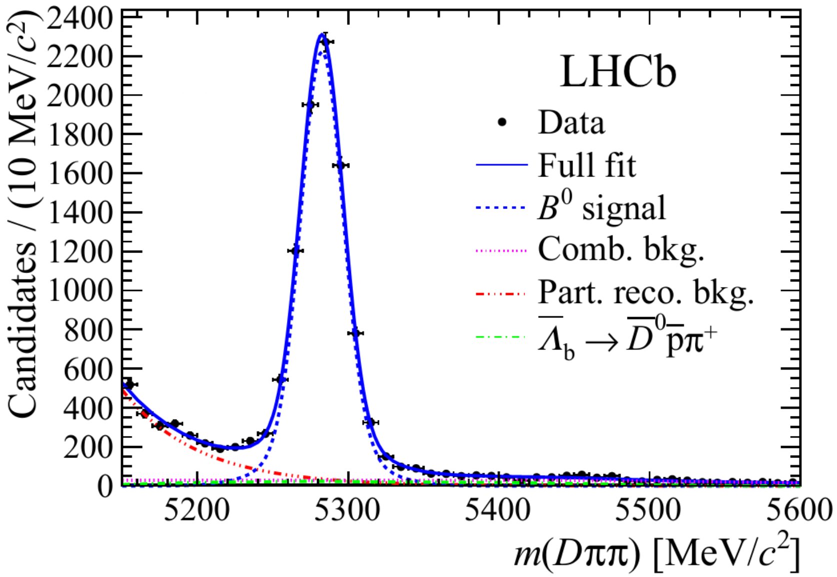
- $B^0_s \to \overline{D}^0K^-\pi^+$ branching fraction not previously measured
  - $B^0_s \to D^{(*)0}K^-\pi^+$ may form an important background to the B^0 mode

- First step towards a measurement of γ is to measure both branching fractions

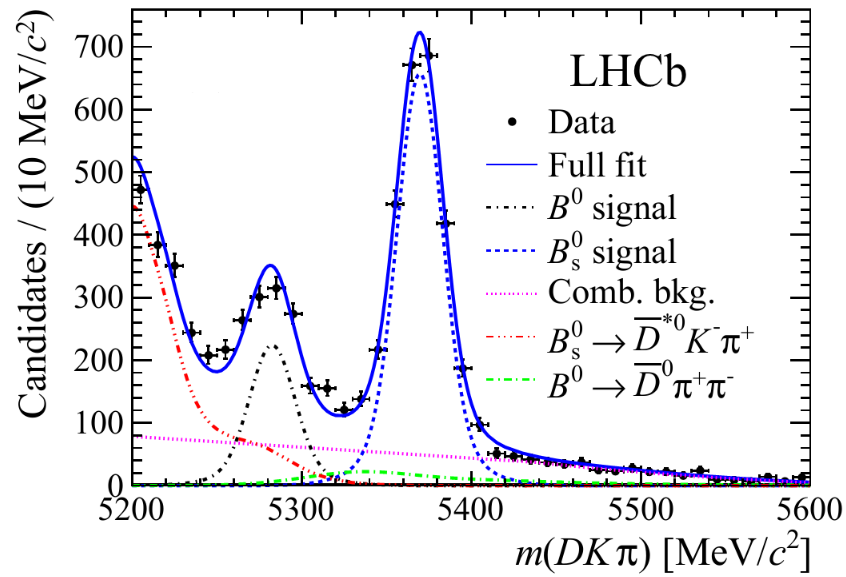


$B^0_{(s)} \to DK\pi$ Mass fits

Normalisation mode ($D\pi\pi$)



Signal mode



Fits to $(K\pi)_D \pi\pi$ and $(K\pi)_D K\pi$ mass distributions from 1fb^{-1} of data

Phys. Rev. D 87, 112009 (2013)

Yields

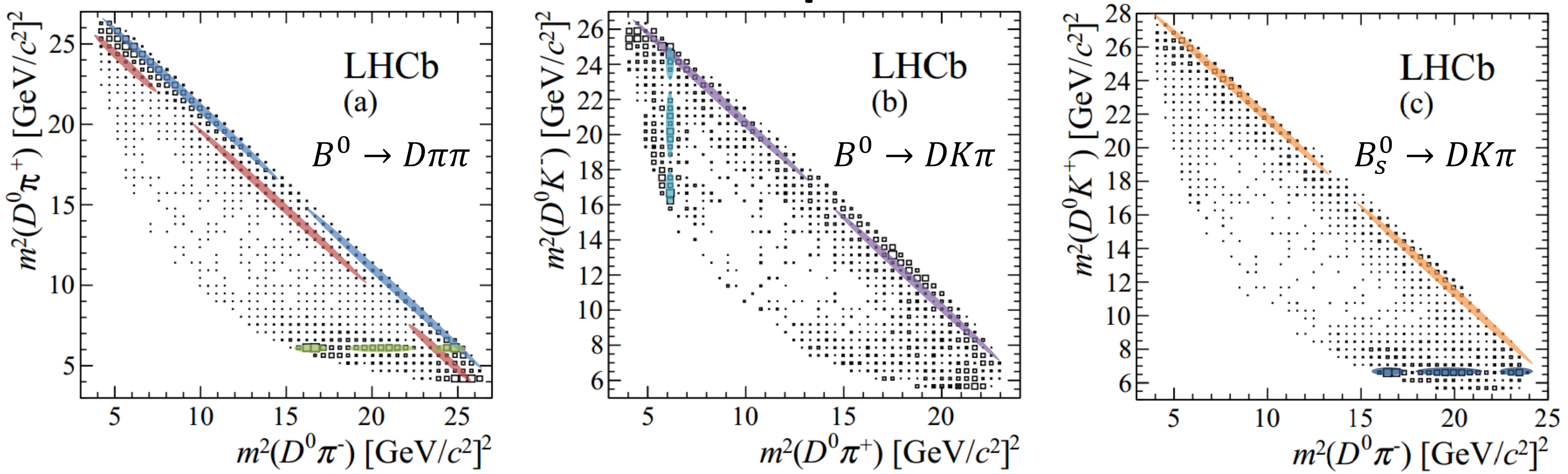
$B^0 \to \overline{D}^0 K^+ \pi^-$: 815 ± 55

$B^0_s \to \overline{D}^0 K^- \pi^+$: 2391 ± 81

$B^0 \to \overline{D}^0 \pi^+ \pi^-$: 8558 ± 134

$B^0_{(s)} \to DK\pi$ Dalitz plots

Phys. Rev. D 87, 112009 (2013)



Efficiency corrected, sWeighted Dalitz plots of:

(a) $B^0 \to \overline{D}^0\pi^+\pi^-$ showing $\rho^0(770)$, $f_2(1270)$, and $D_2^{*-}(2460)$ resonances;

(b) $B^0 \to \overline{D}^0K^+\pi^-$ showing $K^{*0}(892)$ and $D_2^{*-}(2460)$ resonances;

(c) $B_s^0 \to \overline{D}^0K^-\pi^+$ showing $\overline{K}^{*0}(892)$ and $D_{s2}^{*-}(2573)$ resonances.

No amplitude analysis has been performed at this stage.
Quantitative studies of the contents of these Dalitz plots and a measurement of γ will be the subject of future papers.

$B^0_{(s)} \to DK\pi$ Results

- Uncertainties dominated by the normalisation channel branching fraction, the fit model and limited knowledge of f_s/f_d
- First observation of $B_s^0 \to \overline{D}{}^0 K^- \pi^+$ at >10σ significance
- New world best measurement of $B^0 \to \overline{D}{}^0 K^+ \pi^-$ branching fraction

Systematic Uncertainties	B^0	B_s^0
Trigger	1.0%	1.0%
$D^{*\pm}$ veto	< 0.1%	1.0%
$D^\pm$ veto	2.0%	0.2%
$D_s^\pm$ veto	0.2%	0.5%
Simulation statistics	2.0%	2.0%
Modelling of efficiency	3.4%	3.1%
Particle identification	1.0%	1.0%
Fit model	5.0%	2.1%
f_s/f_d	…	7.8%
Total	**6.8%**	**9.0%**

Phys. Rev. D 87, 112009 (2013)

Channel	Branching fraction	Expected
$\mathcal{B}(B^0 \to \overline{D}{}^0 K^+ \pi^-)$	$(9.0 \pm 0.6 \pm 0.6 \pm 0.9) \times 10^{-5}$	$(8.8 \pm 1.7) \times 10^{-5}$
$\mathcal{B}(B_s^0 \to \overline{D}{}^0 K^- \pi^+)$	$(1.00 \pm 0.04 \pm 0.09 \pm 0.10) \times 10^{-3}$	$\mathcal{O}(10^{-3})$

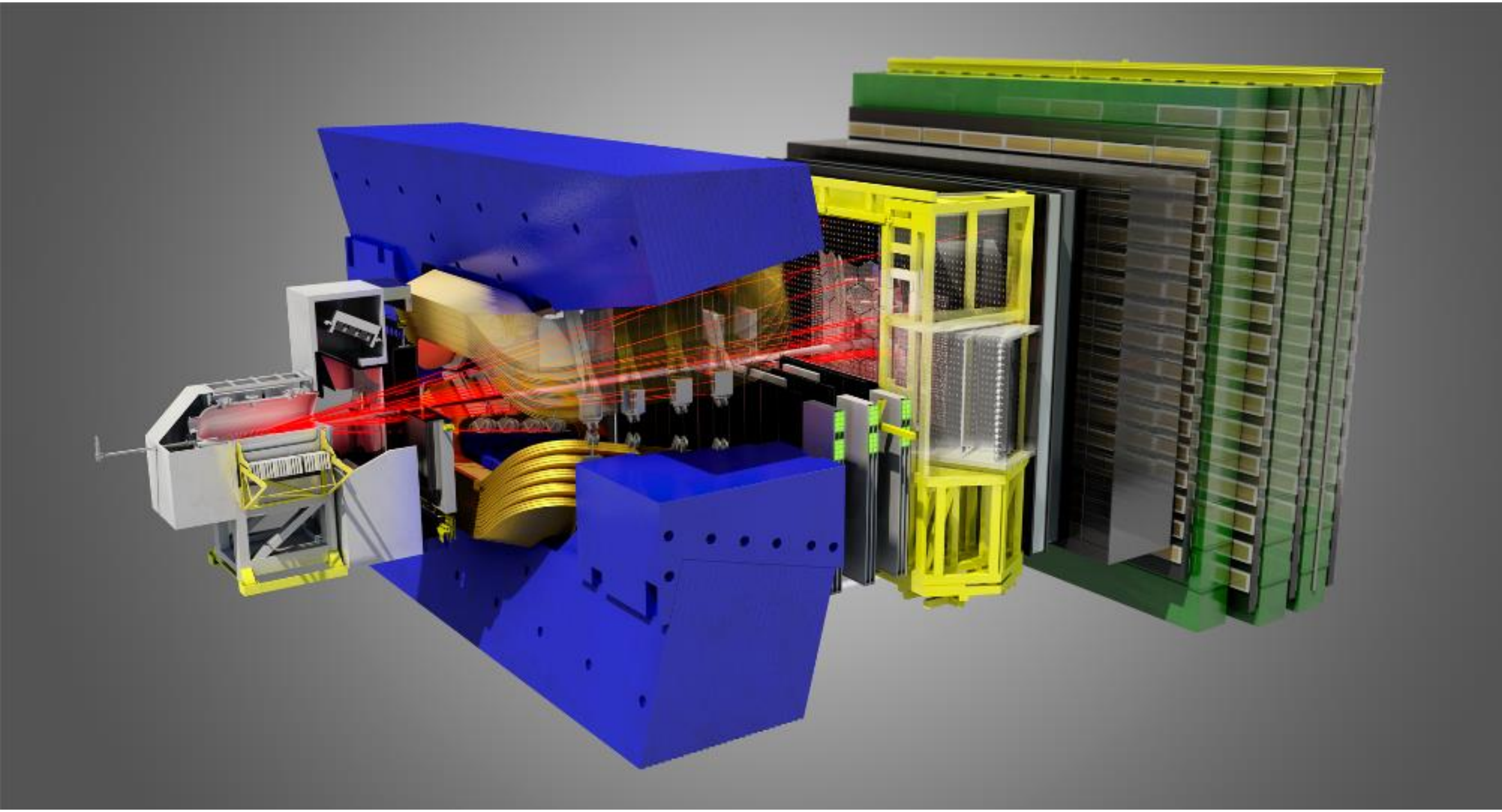
Uncertainties are statistical, systematic and due to the $B^0 \to \overline{D}{}^0 \pi^+ \pi^-$ branching fraction respectively

Summary

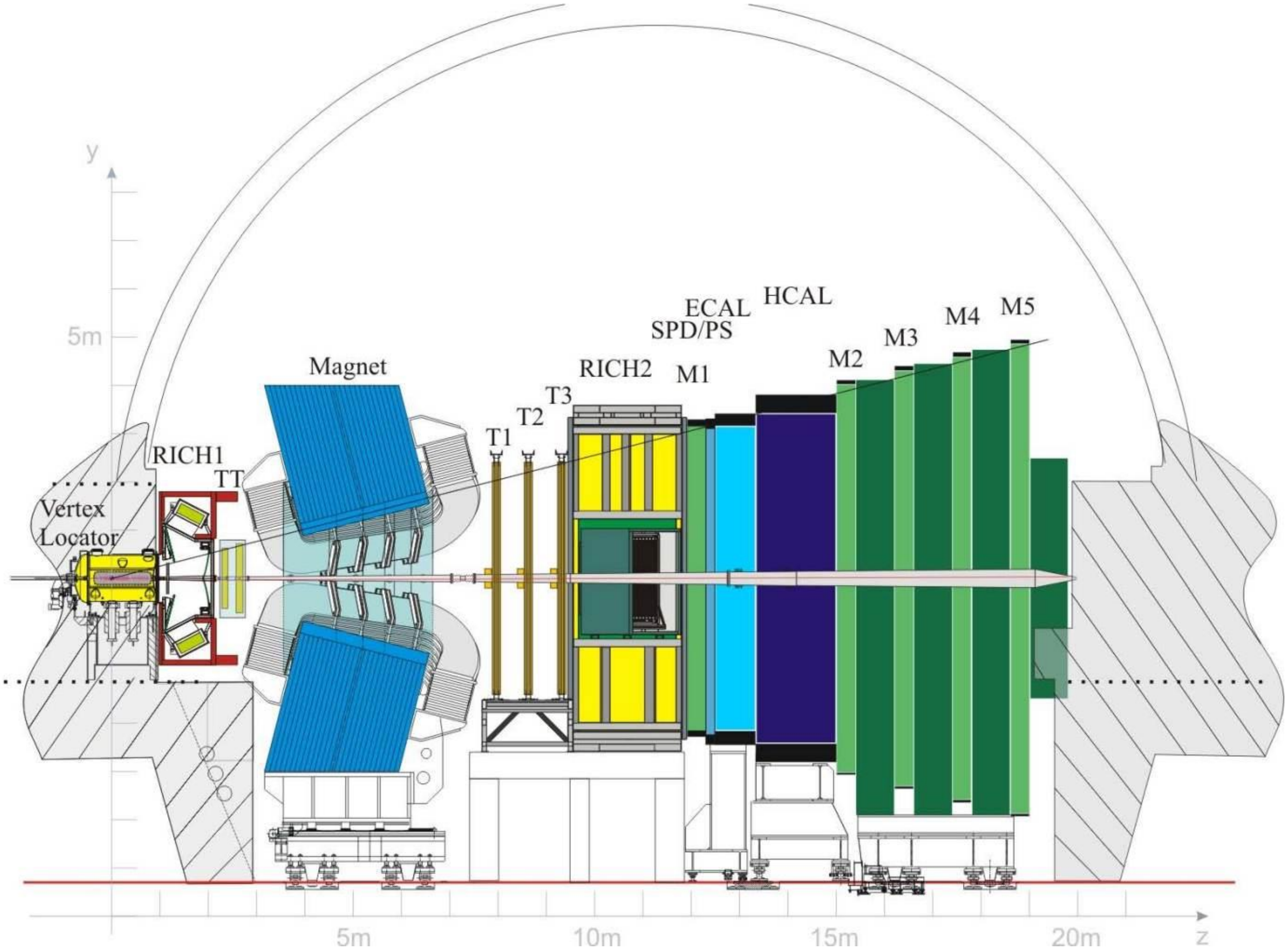
- First γ measurement to use $3fb^{-1}$
  - Combination with $1fb^{-1}$ $B^+ \to DK^+$ GLW/ADS results gives $\gamma = (67 \pm 12)^\circ$
  - Best single experiment γ measurement
  - Expect more $3fb^{-1}$ measurements to follow
- Future γ measurement possible from $B^0 \to \overline{D}^0 K^+ \pi^-$
  - New world best measurement of $B^0 \to \overline{D}^0 K^+ \pi^-$ branching fraction
  - First observation of $B_s^0 \to \overline{D}^0 K^- \pi^+$ at >10σ significance
  - Other channels also available to improve the precision of LHCb γ measurements (e.g. $B_s^0 \to D_s^{\mp} K^{\pm}$, $B^+ \to DK^+ \pi^+ \pi^-$)

Backup

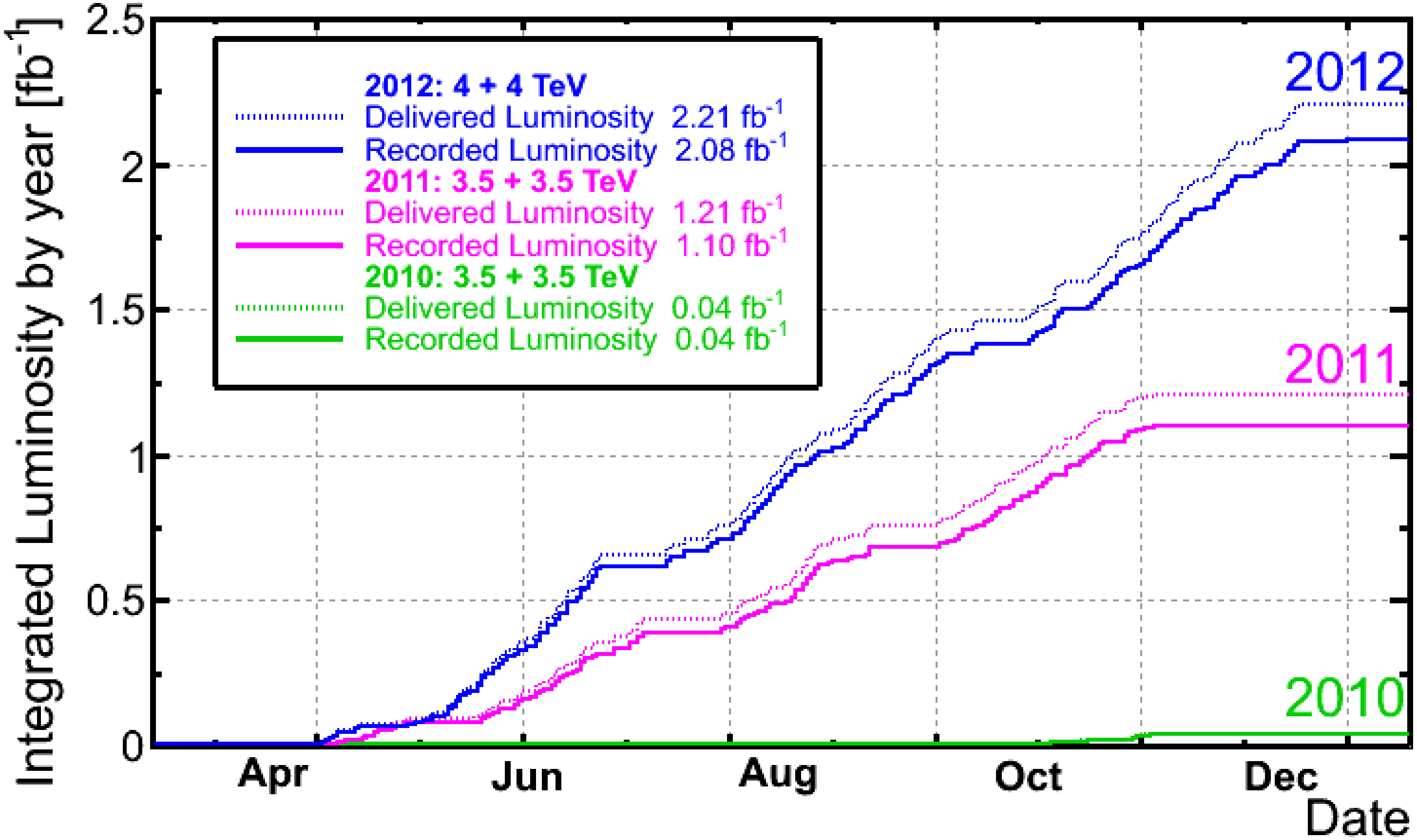
The LHCb Detector



The LHCb Detector



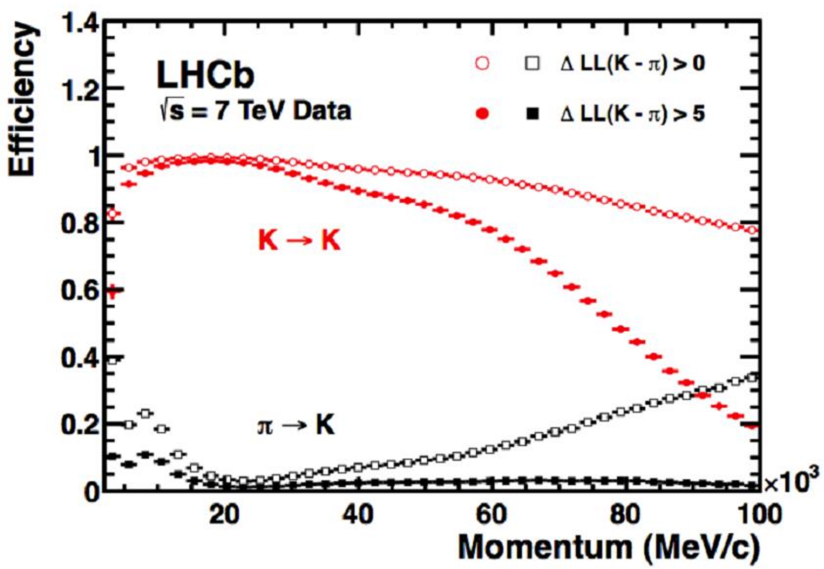
Recorded Luminosity

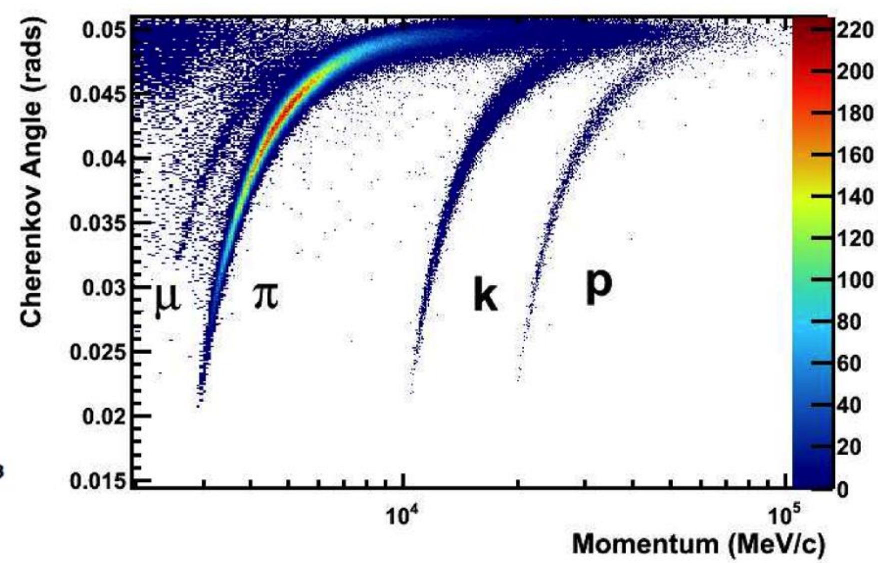


Kaon/pion separation

- Most particle identification information comes from the Ring Imaging Cherenkov detectors.
- Three different radiators provide separation over a wide momentum range.

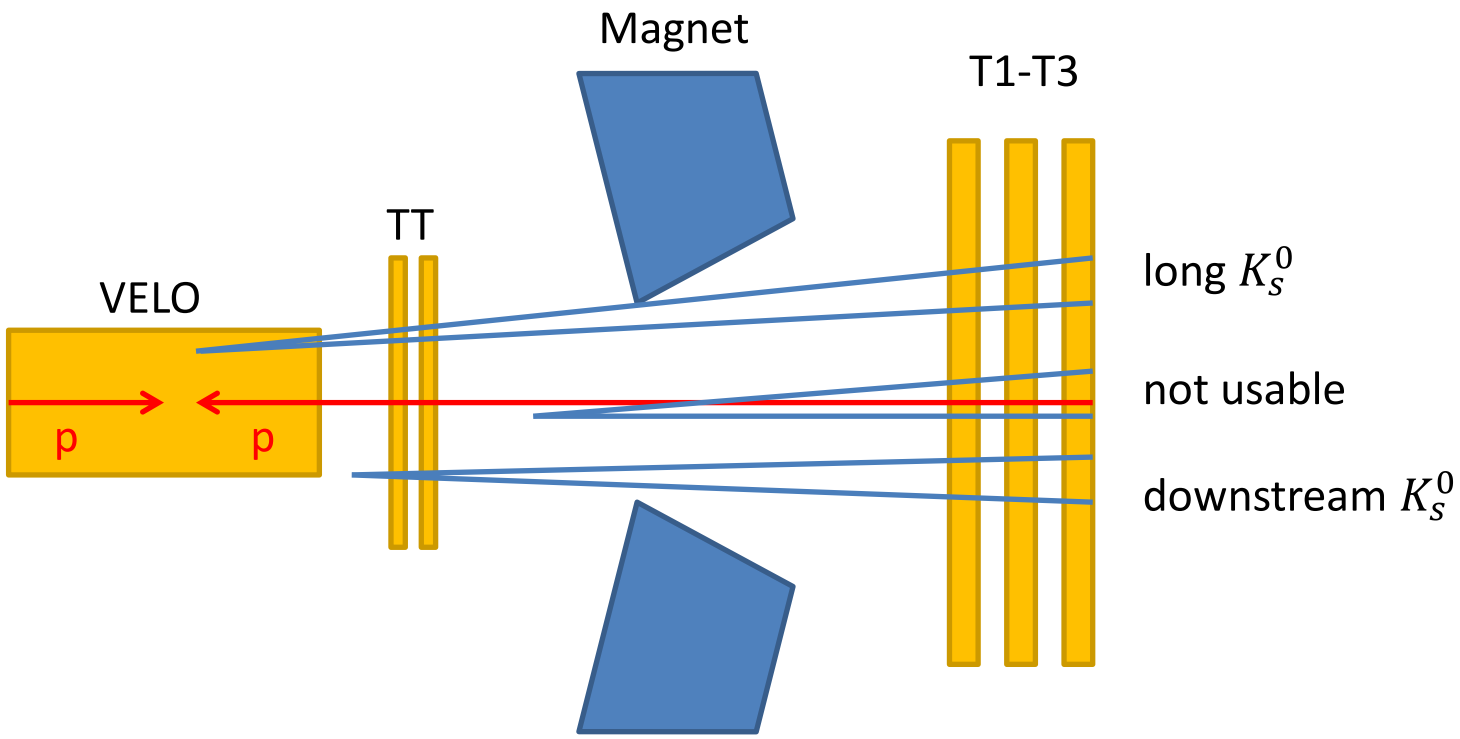
$$\cos\theta = \frac{1}{\beta n}$$





Ks reconstruction

- K_s^0 candidates separated based on where they decayed.
- Around 70% of reconstructible K_s^0 decay downstream of the VELO.
- K_s^0 that decay downstream of the first tracking station are not usable.



γ combination formalism

Likelihood defined as:

$$\mathcal{L}(\vec{\alpha}) = \prod_i f_i\left(\vec{A}_i^{\mathrm{obs}}\middle|\vec{\alpha}\right)$$

where the index i denotes the input measurements and

$$f_i \propto \exp\left(-\frac{1}{2}\left(\vec{A}_i(\vec{\alpha}) - \vec{A}_i^{\mathrm{obs}}\right)^T V_i^{-1}\left(\vec{A}_i(\vec{\alpha}) - \vec{A}_i^{\mathrm{obs}}\right)\right)$$

where $\vec{A}_i$ is a vector of the observables, $\vec{\alpha}$ is a vector of the parameters and V_i is the covariance matrix.

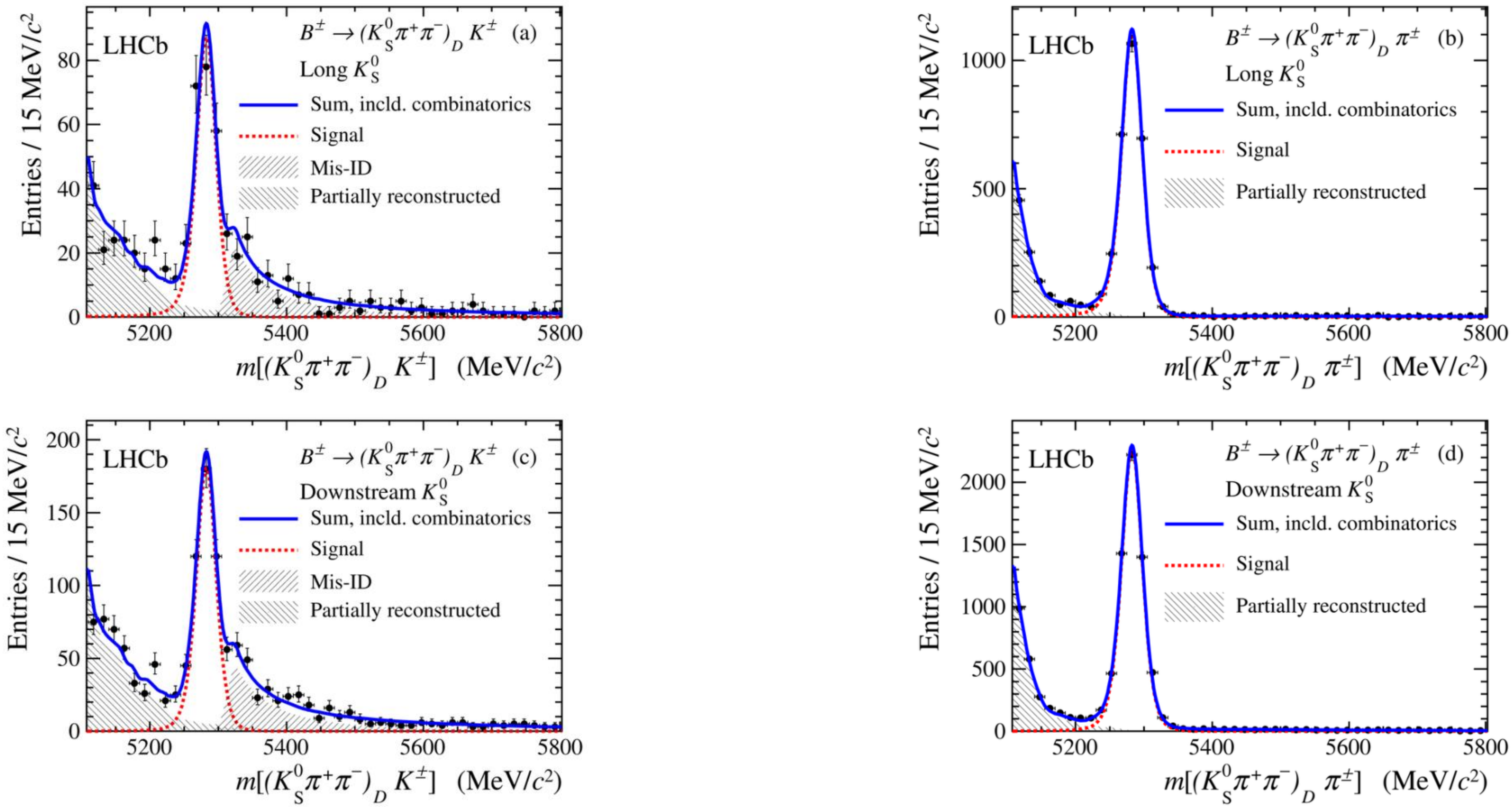
$\mathcal{L}(\vec{\alpha})$ is maximised by minimising $\chi^2(\vec{\alpha}) = -2\ln\mathcal{L}(\vec{\alpha})$.

γ combination formalism

Confidence level for $\gamma = \gamma_0$ is calculated as follows:

- New minimum found $\vec{\alpha}'_{\min}(\gamma_0)$
- $\Delta\chi^2 = \chi^2(\vec{\alpha}'_{\min}) - \chi^2(\vec{\alpha}_{\min})$ is calculated
- Pseudoexperiments, $\vec{A}_j$, are generated from $\mathcal{L}(\vec{\alpha}'_{\min})$
- $\Delta\chi^{2\prime}$ is calculated for each pseudoexperiment
- $1 - \mathrm{CL}$ is the fraction of pseudoexperiments that perform worse than data ($\Delta\chi^2 < \Delta\chi^{2\prime}$)

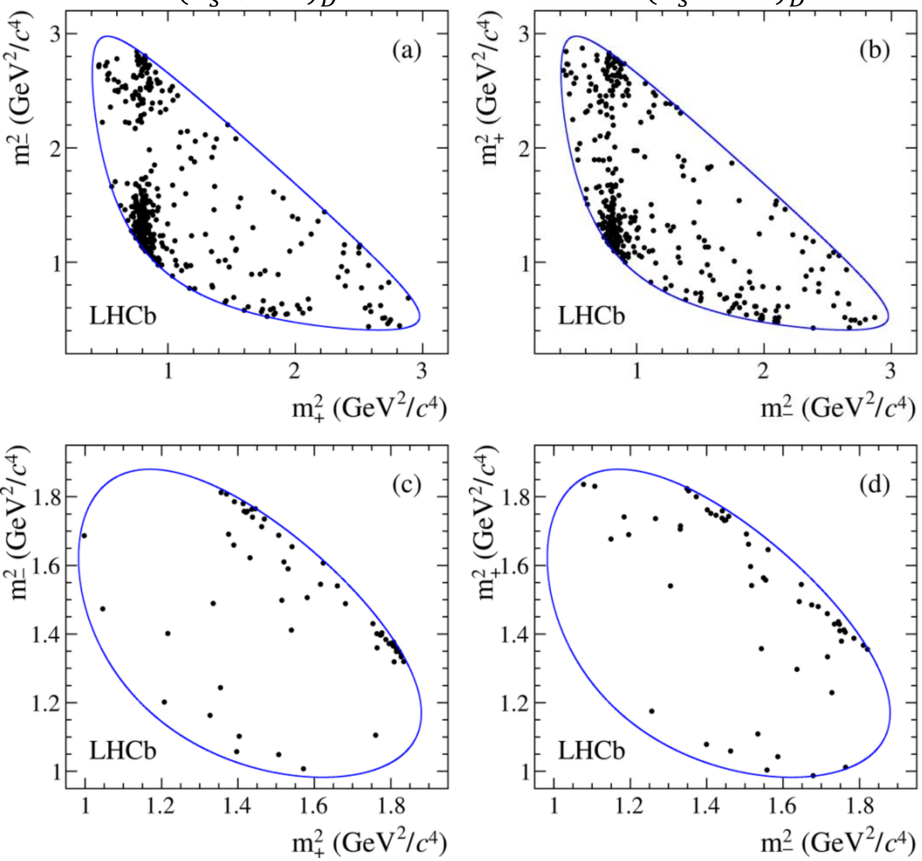
γ combination inputs GGSZ (1fb^{-1})



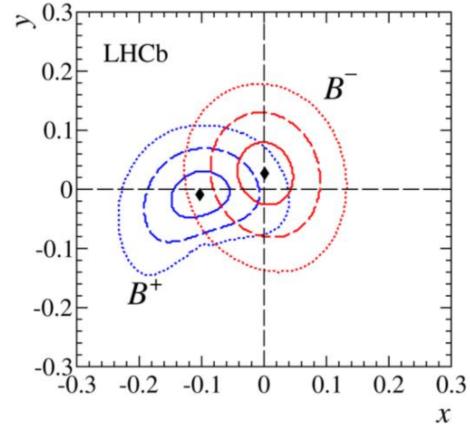
Phys Lett B 718 (2012), 43-55

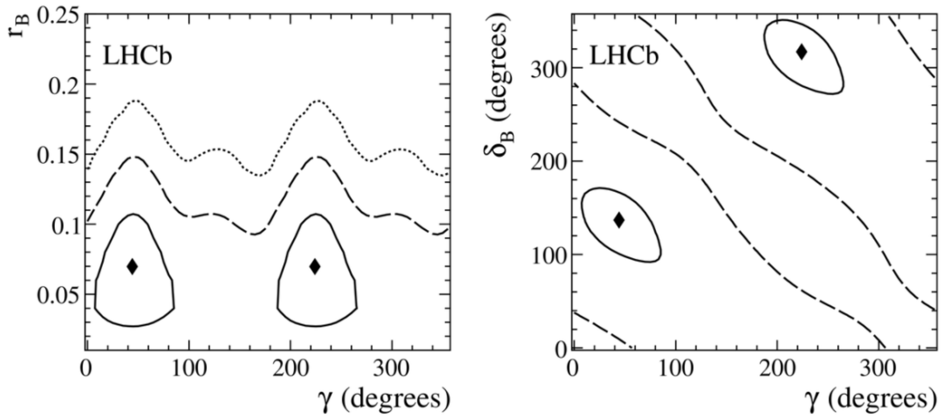
γ combination inputs GGSZ (1fb^{-1})

$B^+ \to (K_S^0\pi^+\pi^-)_D K^+$ $B^- \to (K_S^0\pi^+\pi^-)_D K^-$



$B^+ \to (K_S^0 K^+ K^-)_D K^+$ $B^- \to (K_S^0 K^+ K^-)_D K^-$





Phys Lett B 718 (2012), 43-55

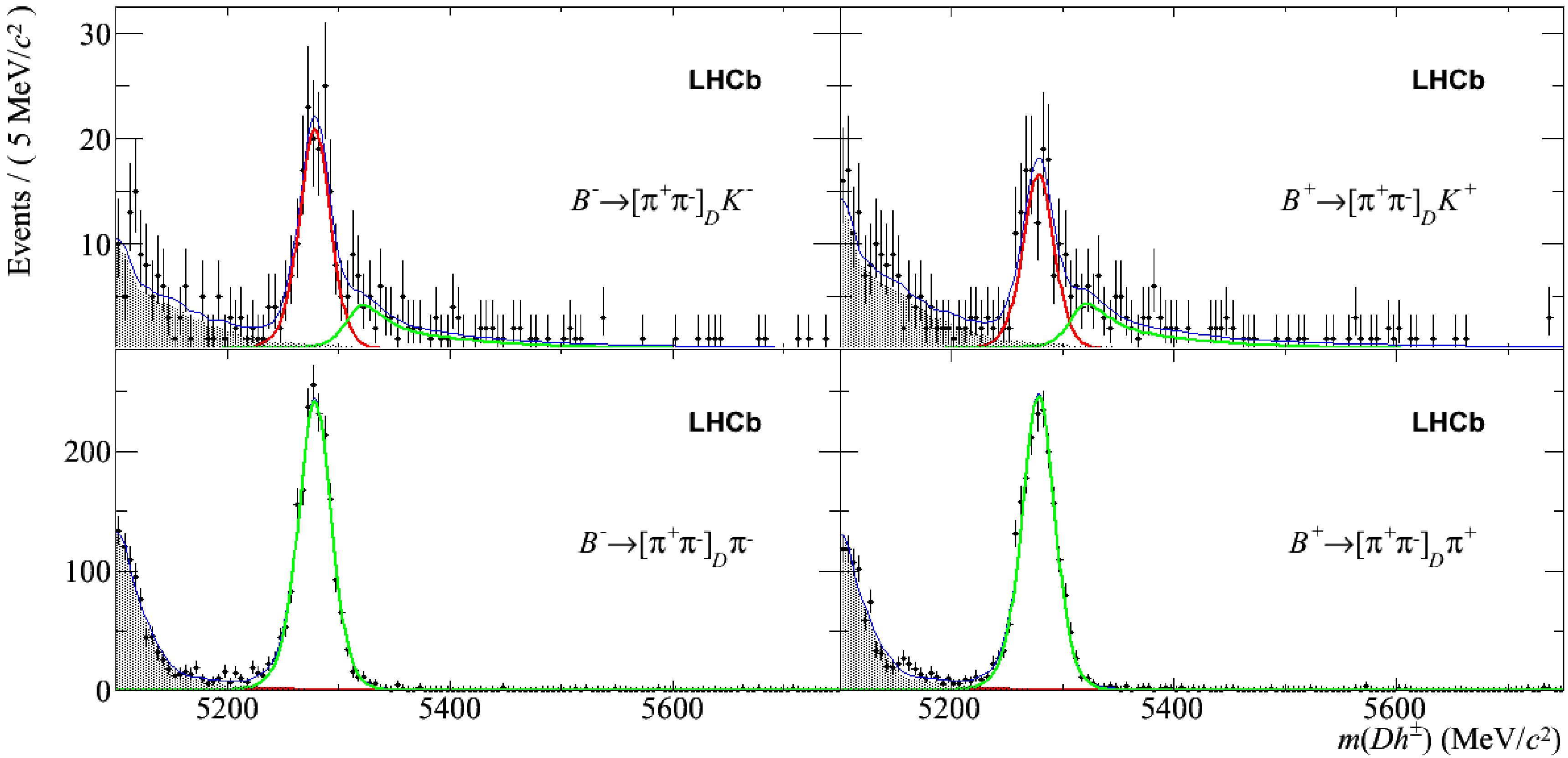
γ combination inputs GGSZ (1fb^{-1})

$$x_+ = (-10.3 \pm 4.5 \pm 1.8 \pm 1.4) \times 10^{-2}$$
$$x_- = (0.0 \pm 5.2 \pm 0.8 \pm 2.3) \times 10^{-2}$$
$$y_+ = (-0.9 \pm 3.7 \pm 0.8 \pm 3.0) \times 10^{-2}$$
$$y_- = (2.7 \pm 5.2 \pm 0.8 \pm 2.3) \times 10^{-2}$$

Uncertainties are statistical, systematic and due to the strong phase measurements used in the fit respectively

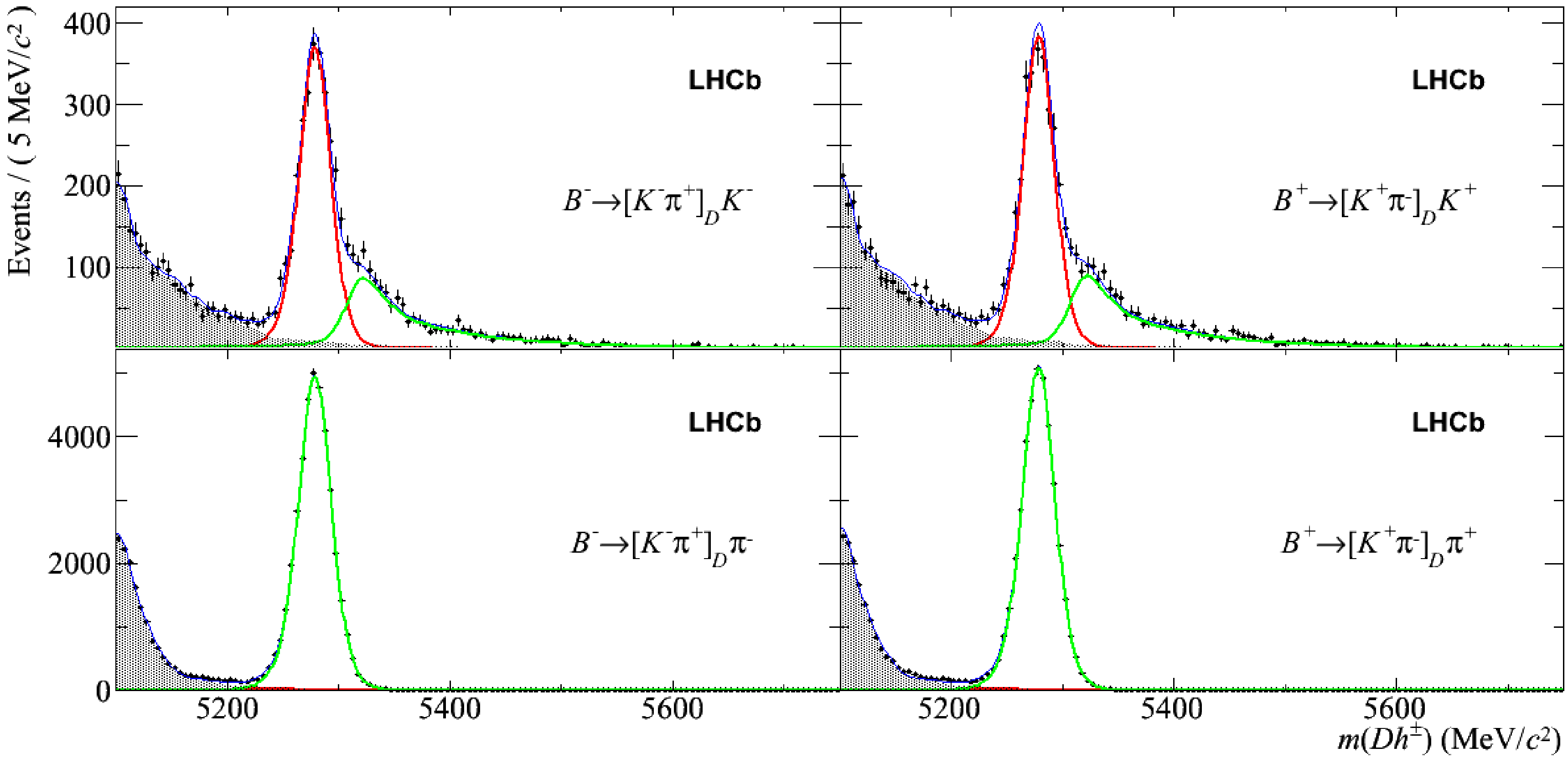
Phys Lett B 718 (2012), 43-55

γ combination inputs 2 body GLW/ADS ($1fb^{-1}$)



Phys Lett B 712 (2012), 203-212

γ combination inputs 2 body GLW/ADS ($1fb^{-1}$)



Phys Lett B 712 (2012), 203-212

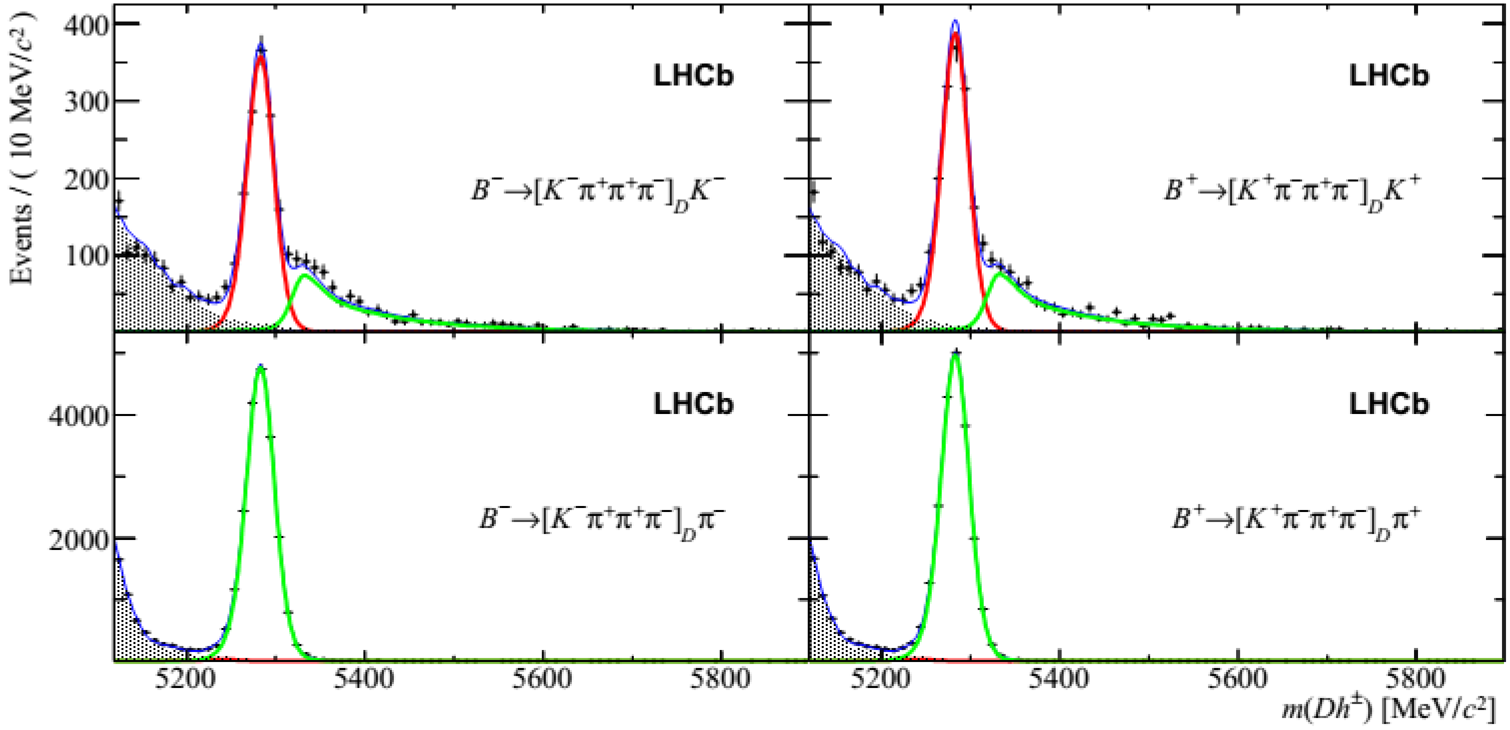
γ combination inputs 2 body GLW/ADS (1fb^{-1})

$$R_{K/\pi}^{K\pi} = 0.0774 \pm 0.0012 \pm 0.0018$$
$$R_{K/\pi}^{KK} = 0.0773 \pm 0.0030 \pm 0.0018$$
$$R_{K/\pi}^{\pi\pi} = 0.0803 \pm 0.0056 \pm 0.0017$$
$$A_{\pi}^{K\pi} = -0.0001 \pm 0.0036 \pm 0.0095$$
$$A_{K}^{K\pi} = 0.0044 \pm 0.0144 \pm 0.0174$$
$$A_{\pi}^{KK} = -0.020 \pm 0.009 \pm 0.012$$
$$A_{K}^{KK} = 0.148 \pm 0.037 \pm 0.010$$
$$A_{\pi}^{\pi\pi} = -0.001 \pm 0.017 \pm 0.010$$
$$A_{K}^{\pi\pi} = 0.135 \pm 0.066 \pm 0.010$$
$$R_{K}^{-} = 0.0073 \pm 0.0023 \pm 0.0004$$
$$R_{K}^{+} = 0.0232 \pm 0.0034 \pm 0.0007$$
$$R_{\pi}^{-} = 0.00469 \pm 0.00038 \pm 0.00008$$
$$R_{\pi}^{+} = 0.00352 \pm 0.00033 \pm 0.00007$$

Phys Lett B 712 (2012), 203-212

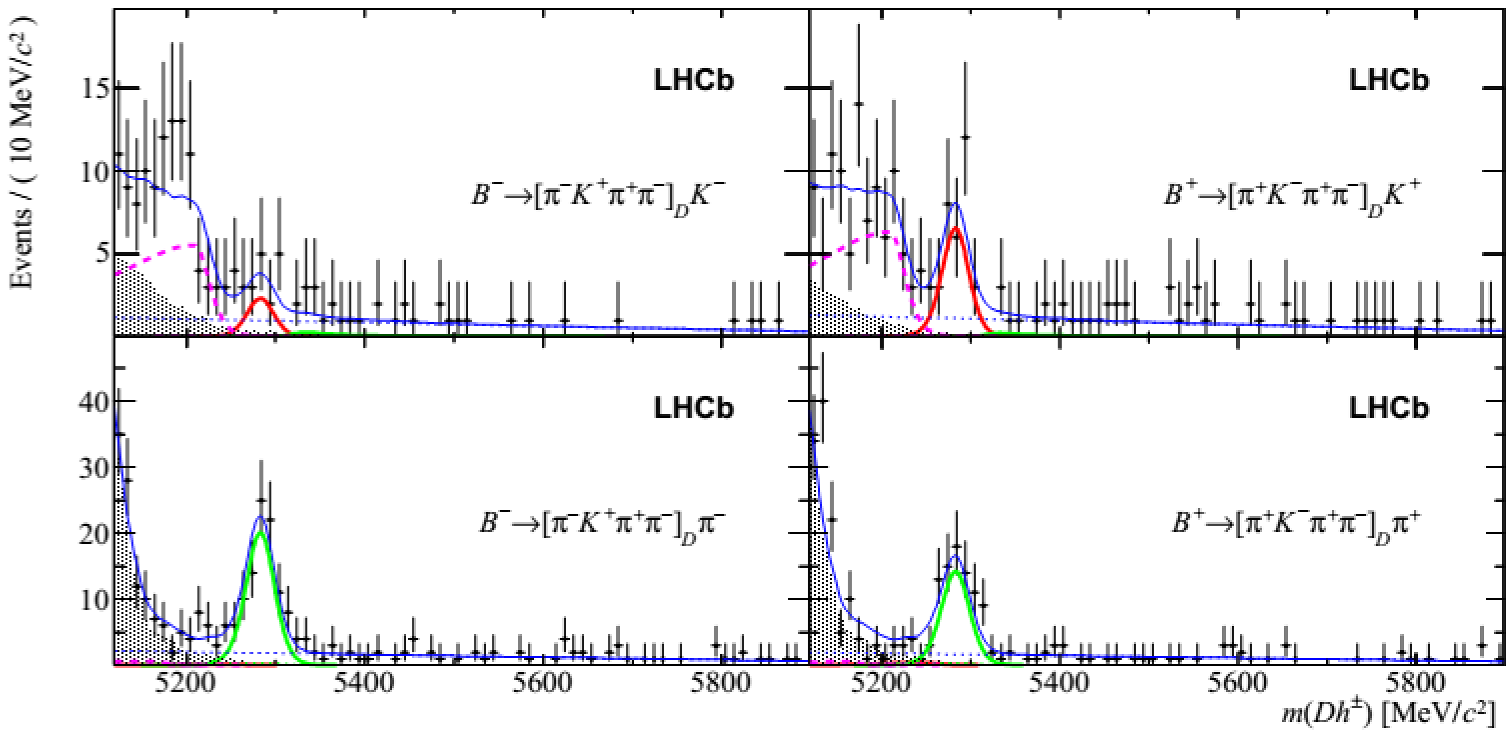
Uncertainties are statistical and systematic respectively

γ combination inputs 4 body ADS ($1fb^{-1}$)



Phys Lett B 723 (2013), 44-53

γ combination inputs
4 body ADS (1fb^{-1})



Phys Lett B 723 (2013), 44-53

γ combination inputs 4 body ADS ($1fb^{-1}$)

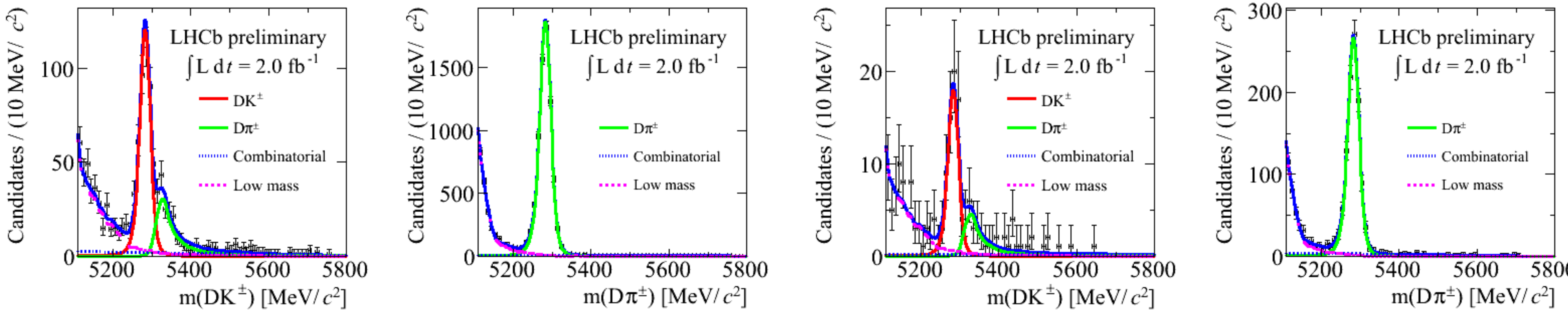
$$R_{K/\pi}^{K3\pi} = 0.0765 \pm 0.0017 \pm 0.0026$$
$$A_{\pi}^{K3\pi} = -0.006 \pm 0.005 \pm 0.010$$
$$A_{K}^{K3\pi} = -0.026 \pm 0.020 \pm 0.018$$
$$R_{K-}^{K3\pi} = 0.0071 \pm 0.0034 \pm 0.0008$$
$$R_{K+}^{K3\pi} = 0.0155 \pm 0.0042 \pm 0.0010$$
$$R_{\pi-}^{K3\pi} = 0.00400 \pm 0.00052 \pm 0.00011$$
$$R_{\pi+}^{K3\pi} = 0.00316 \pm 0.00046 \pm 0.00011$$

Phys Lett B 723 (2013), 44-53

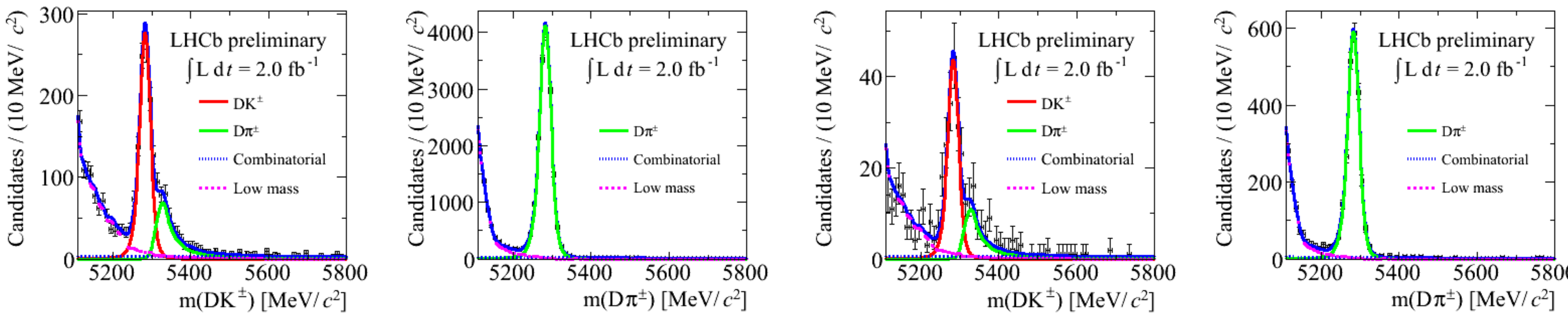
Uncertainties are statistical and systematic respectively

γ combination inputs GGSZ ($2fb^{-1}$)

Long K_S^0



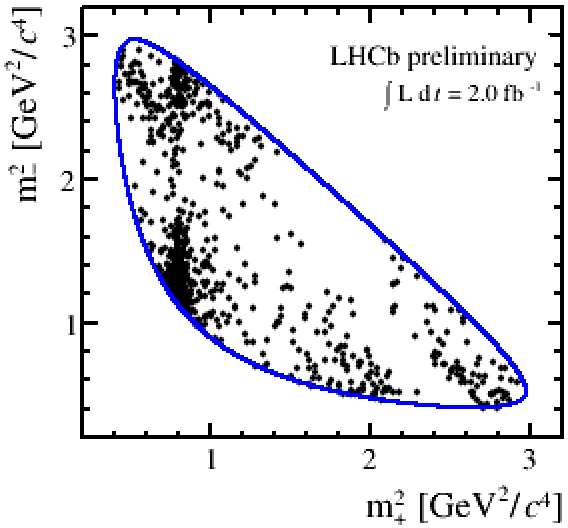
Downstream K_S^0



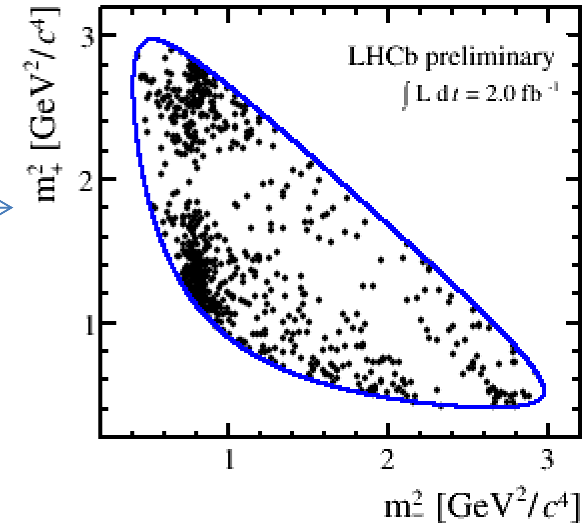
$B^+ \to (K_S^0\pi^+\pi^-)_D K^+$ $B^- \to (K_S^0\pi^+\pi^-)_D K^-$ $B^+ \to (K_S^0 K^+ K^-)_D K^+$ $B^- \to (K_S^0 K^+ K^-)_D K^-$

LHCb-CONF-2013-004

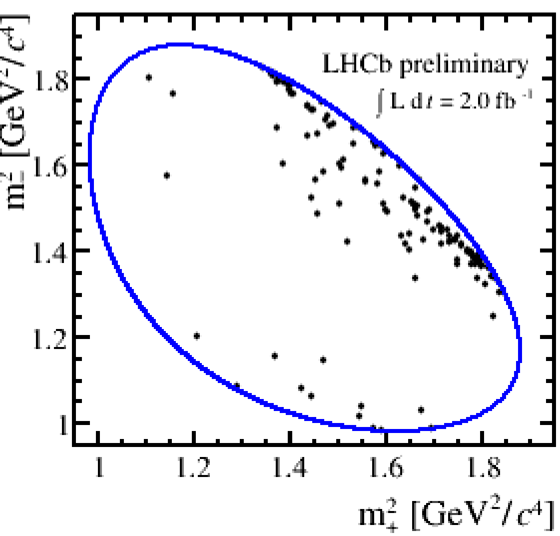
γ combination inputs GGSZ (2fb^{-1})



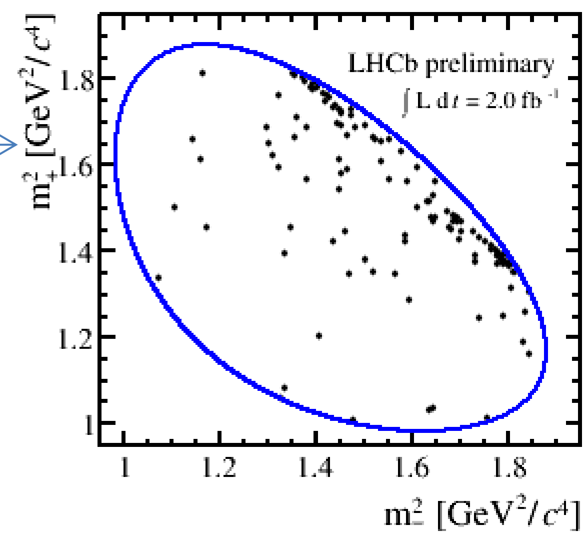
$B^- \to (K_S^0\pi^+\pi^-)_D K^-$



$B^+ \to (K_S^0\pi^+\pi^-)_D K^+$



$B^- \to (K_S^0K^+K^-)_D K^-$



$B^+ \to (K_S^0K^+K^-)_D K^+$

LHCb-CONF-2013-004

γ combination inputs GGSZ (2fb^{-1})

$$x_+ = (-8.7 \pm 3.1 \pm 1.6 \pm 0.6) \times 10^{-2}$$
$$x_- = (5.3 \pm 3.2 \pm 0.9 \pm 0.9) \times 10^{-2}$$
$$y_+ = (0.1 \pm 3.6 \pm 1.4 \pm 1.9) \times 10^{-2}$$
$$y_- = (9.9 \pm 3.6 \pm 2.2 \pm 1.6) \times 10^{-2}$$

Uncertainties are statistical, systematic and due to the strong phase measurements used in the fit respectively

LHCb-CONF-2013-004