Tree-level measurements of γ

Chris Thomas (Oxford University)

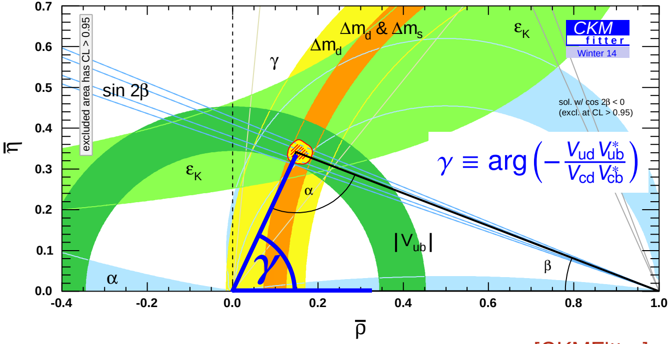
On behalf of the LHCb collaboration

Implications of LHCb measurements and future prospects 2014

16 October 2014

CKM angle γ

CKM matrix encapsulates weak quark interactions.
Defines a Unitarity Triangle on the complex plane:

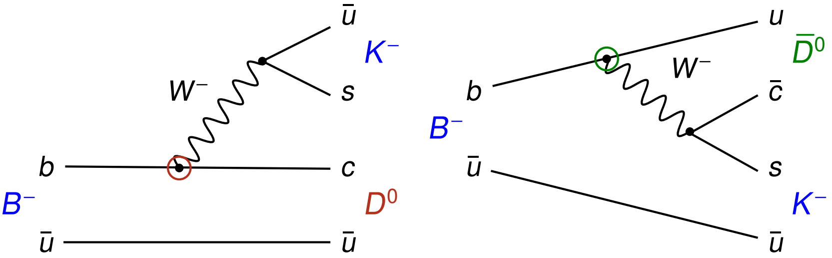


[CKMFitter]

γ is the least well-known of the angles from direct measurements.

Measurements of γ with $B \to DK$

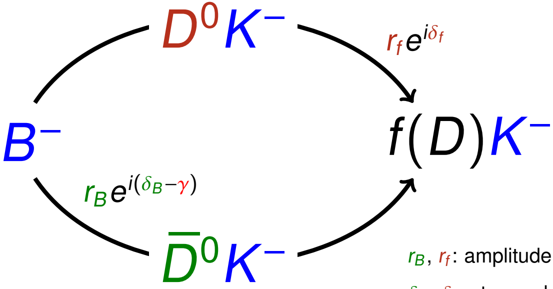
γ can be measured cleanly with decays of the form $B \to DK$.
Exploits the interference between $b \to c$ and $b \to u$ transitions.
Example diagrams for $B^- \to DK^-$:



Key point: D^0 and $\bar{D}^0$ must decay to the same final state $f(D)$.
Charged $B^{\pm}$ decay is tree-level with negligible loop contributions.
Irreducible theoretical uncertainty $\delta\gamma/\gamma \lesssim \mathcal{O}(10^{-7})$ [JHEP 1401 (2014) 051].
'Standard candle' against which other γ measurements, sensitive to New Physics, can be compared.

Measurements of γ with $B \to DK$

Two potential decay paths for B^- decays:



r_B, r_f: amplitude ratios

δ_B, δ_f: strong phase differences

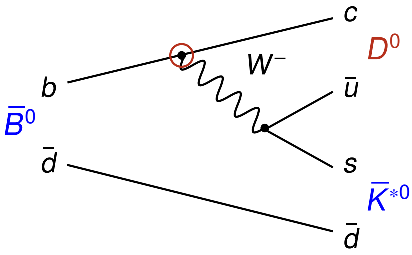
Many potential final states $f(D)$:

- h^+h^- (ADS/GLW)
- $K^\pm\pi^\mp\pi^+\pi^-$ (Multibody ADS)
- $K^0_S K^\pm \pi^\mp$ (GLS)
- $K^0_S h^+ h^-$ ($h = \pi, K$) (GGSZ/B)

Analyses share several common features

Additional measurements of γ

- $B^{\pm} \to D\pi^{\pm}$ decays are also sensitive to γ:
  - Smaller interference r_B^{π} (~ 0.01 compared to ~ 0.1 in $B^{\pm} \to DK^{\pm}$)
  - Larger branching fraction
- Neutral analogue $B^0 \to DK^{*0}$:



  Larger interference in this case; $r_{B^0} \sim 0.3$. Self-tagging due to K^{*0}.
- Can also perform time-dependent γ measurements with $B_s^0 \to D_s K$.
- Will overview LHCb results for these channels and mention challenges and expectations for the future.

Tree-level γ at LHCb

$B^\pm \to D(h^+h^-)h^\pm$: ADS/GLW

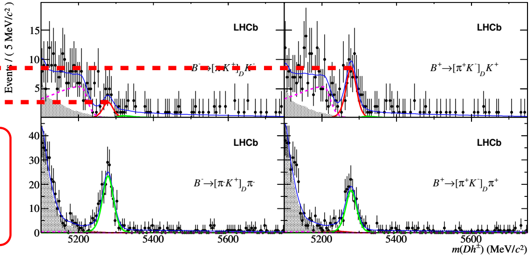
D^0 decays to two-body final states:

- K^+K^-, $\pi^+\pi^-$ (CP eigenstates)
- $K^\pm\pi^\mp$ (CF and DCS decays)

Measure ratios and asymmetries, e.g.:

$$R_h^\pm = \frac{\Gamma(B^\pm \to D_{\mathrm{DCS}} h^\pm)}{\Gamma(B^\pm \to D_{\mathrm{CF}} h^\pm)} = \frac{(r_B^h)^2 + r_f{}^2 + 2r_B^h r_f \cos(\delta_B^h + \delta_f \pm \gamma)}{1 + (r_B^h r_f)^2 + 2r_B^h r_f \cos(\delta_B^h - \delta_f \pm \gamma)}$$

CPV



$DK^\pm$

$D\pi^\pm$

LHCb 1 fb^{-1}. 3 fb^{-1} coming soon!

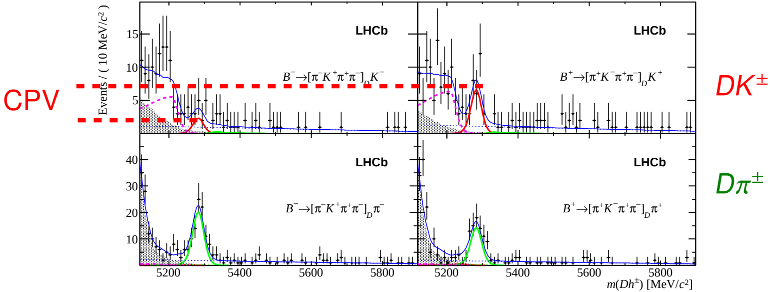
Charm parameters r_f, δ_f constrained by external measurements.

Multibody ADS

Extend ADS method to multibody modes ($K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$, $K^{\pm}\pi^{\mp}\pi^{0}$, ...)
Amplitude now varies across D^0 phase space
Term containing γ is modified as follows:

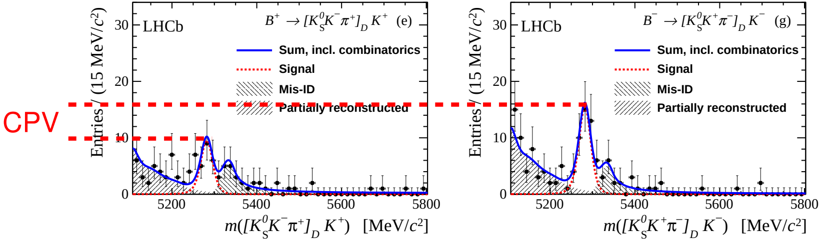
$$2r_B^h r_f \cos(\delta_B^h + \delta_f \pm \gamma) \rightarrow 2r_B^h r_f \kappa_D \cos(\delta_B^h + \delta_f \pm \gamma)$$

The quantity $\kappa_D \in [0,1]$ is the coherence factor.
LHCb measurement of $B^{\pm} \rightarrow D(K^{\pm}\pi^{\mp}\pi^{+}\pi^{-})h^{\pm}$ with 1 fb^{-1}:

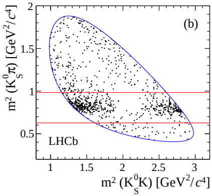


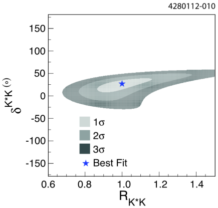
$B^\pm \to D(K^0_S K^\pm \pi^\mp)K^\pm$: GLS

First measurement of this channel, using 3 fb^{-1} of LHCb data.



Measure both across all phase space and in coherent $K^{*\pm}$ region:





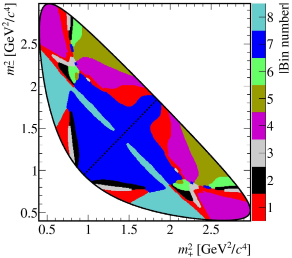
CLEO-c coherence factor near $K^{*\pm} \sim 1$

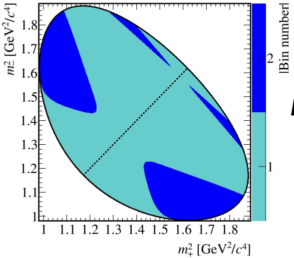
[PRD 85 (2012) 092016]

Model-independent $B^{\pm} \to D(K^0_S h^+ h^-)K^{\pm}$: GGSZ

Measurement on 3 fb^{-1} of LHCb data. Update of [PLB 718 (2012) 43].
CP violation manifested in B^+–B^- differences over the $K^0_S h^+ h^-$ Dalitz plot.
Divide the Dalitz plot into bins optimised for statistical sensitivity:

$K^0_S \pi^+ \pi^-$



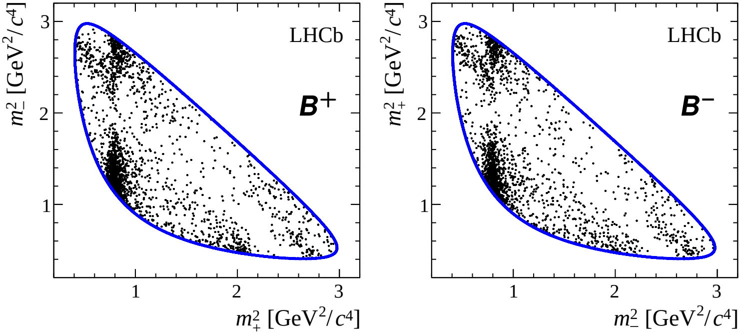


$K^0_S K^+ K^-$

Yield of B^+ and B^- measured in each Dalitz plot bin and used to infer γ.
Must account for $D^0 \to K^0_S h^+ h^-$ strong phase variation across Dalitz plot; use quantum-correlated measurements from CLEO-c [PRD 82 (2010) 112006]

$K_S^0\pi^+\pi^-$ Dalitz plots

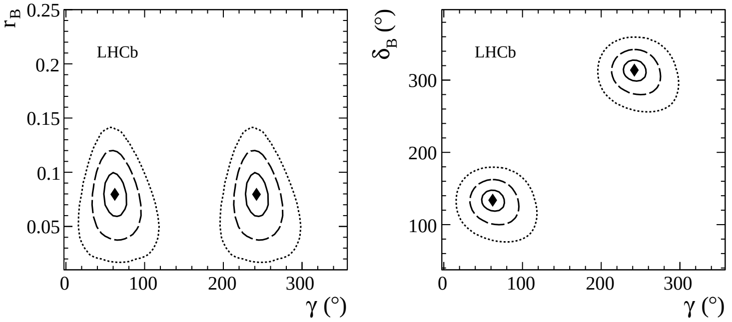
$K_S^0\pi^+\pi^-$ data ($\sim$ 2600 candidates):



$m_\pm^2 \equiv m^2(K_S^0\pi^\pm)$

Results

Confidence intervals on γ and the hadronic parameters r_B, δ_B:

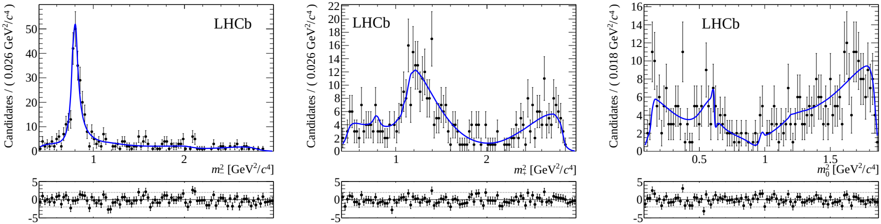


$$\gamma = (62^{+15}_{-14})^\circ$$ (Stat. + syst.)

Most precise determination from a single measurement.
$r_B = 0.080^{+0.019}_{-0.021}$, $\delta_B = (134^{+14}_{-15})^\circ$.

Model-dependent $B^\pm \to D(K^0_S h^+ h^-)K^\pm$: GGSZ

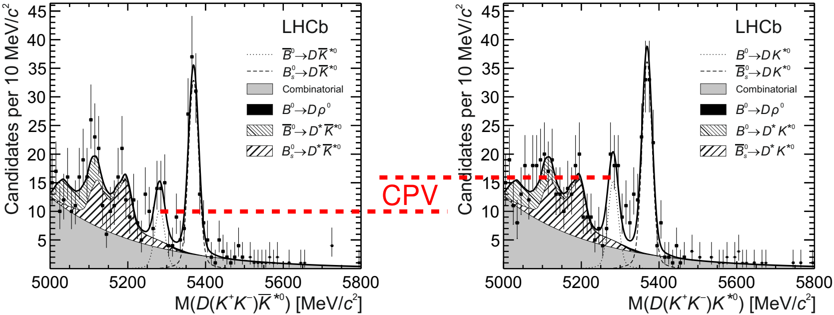
Alternative approach performed on 1 fb^{-1} of LHCb data.
Unbinned across Dalitz plot. Use a D^0 decay model developed at BaBar [PRL 105 (2010) 121801], [PRL 105 (2010) 081803].
Optimal statistical precision; model-related uncertainty.
Dalitz plot projections:



Find $\gamma = (84^{+49}_{-42})^\circ$.
Results compatible with (but cannot be combined with) MI approach.

$B^0 \rightarrow DK^{*0}$: ADS/GLW

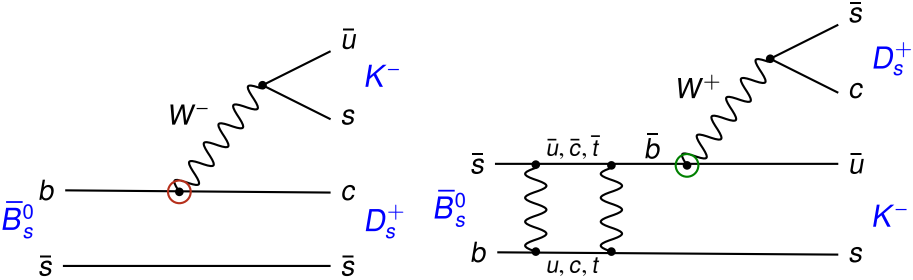
Measurement with 3 fb^{-1} of LHCb data.
Must consider coherence of K^{*0} resonance; constrained with $B^0 \rightarrow D^0 K^{\pm}\pi^{\mp}$ model ($\sim$ 95%).
Mass plots for $B^0 \rightarrow D(K^+K^-)K^{*0}$:



Suppressed decay significance 2.9σ.
Measurement of $B^0 \rightarrow D(K_S^0 h^+ h^-)K^{*0}$ also in the pipeline.

Time-dependent measurement of γ: $B_s^0 \to D_s K$

Interference between $b \to c$ and $b \to u$ transitions facilitated by mixing in the B_s^0–$\bar{B}_s^0$ system.



Amplitude ratio $r_{D_sK} \equiv \left| \frac{\mathcal{A}(\bar{B}_s^0 \to D_s^- K^+)}{\mathcal{A}(B_s^0 \to D_s^- K^+)} \right| \simeq 0.5$

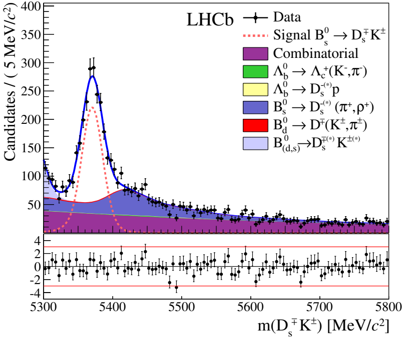
Time-dependent analysis. Must tag initial B_s^0 flavour.

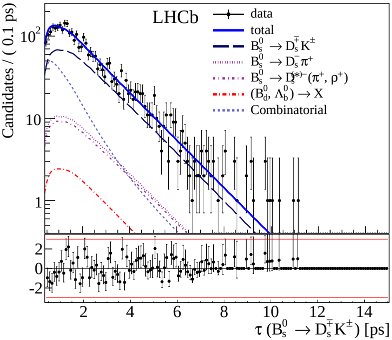
Measure $-2\beta_s + \gamma$, constraining $-2\beta_s$ with external measurements.

Can also measure CPV in $B^0 \to D^\pm \pi^\mp$, but reduced in magnitude.

$B_s^0 \to D_s K$

LHCb measurement of 1 fb^{-1}.
Measures the five CP observables C_f, S_f, $S_{\bar{f}}$, $A_f^{\Delta\Gamma}$, $A_{\bar{f}}^{\Delta\Gamma}$.
Orthogonal systematics to time-integrated measurements.
Mass and decay time fits:

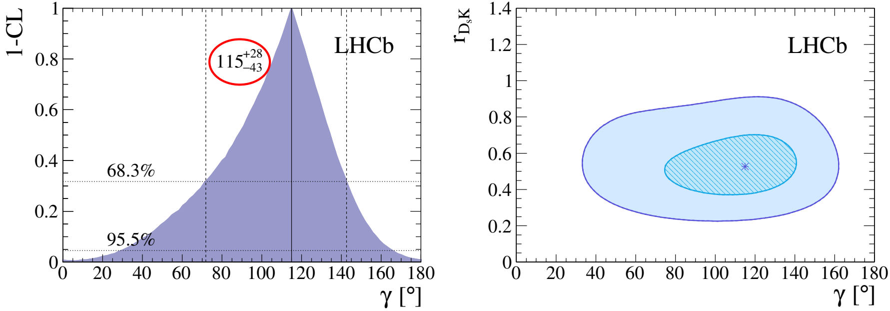




About 1800 signal events. Tagging power $\sim 5\%$.

$B_s^0 \to D_s K$

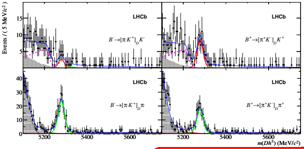
Resultant influence on γ (stat. + syst.):

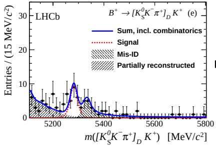


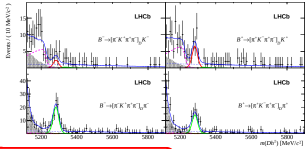
$r_{D_sK} = 0.53^{+0.16}_{-0.17}$
Anticipate 3 fb^{-1} precision about 20°.

LHCb γ combination

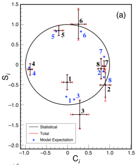
LHCb γ combination

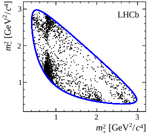






Perform a combined determination of γ using LHCb measurements (+ external inputs).
Several decay modes share common parameters.
Potentially nontrivial correlations → global fit.
Most recent combination early September 2014.
Both frequentist and Bayesian approaches.





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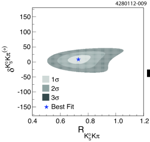
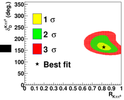
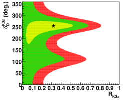
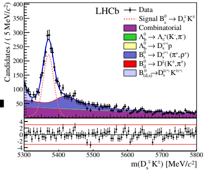
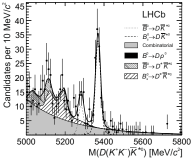




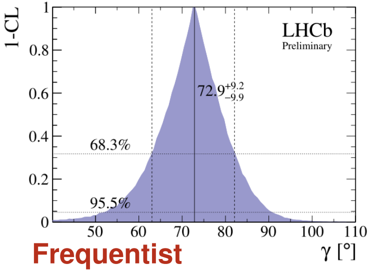


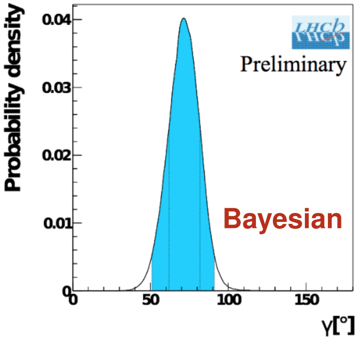




LHCb γ combination

Combination of $B^{\pm} \to DK^{\pm}$, $B^0 \to D^0 K^{*0}$ and $B_s^0 \to D_s K$ results:





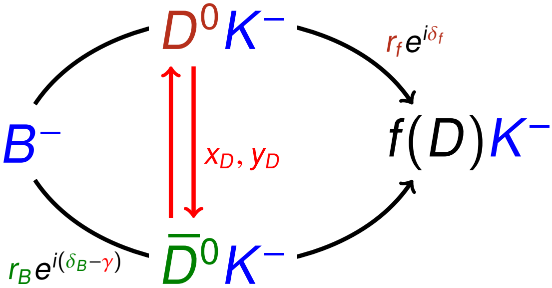
Values of γ:

- Frequentist: 72.9° with 68% CI [63.0°, 82.1°]
- Bayesian: 71.9° with 68% CI [61.9°, 81.8°]

Most precise results from a single experiment – more precise than combined B-factories. For combination including $B^{\pm} \to D\pi^{\pm}$, see backup.

D^0 mixing

D^0 mixing has a nontrivial influence on γ determination
(e.g. [PRD 72 (2005) 031501], [PRD 89 (2014) 014021])



Corresponding bias on $\gamma \sim 1^\circ$ for $B^\pm \to DK^\pm$.
More significant effect for $B^\pm \to D\pi^\pm$. Bias $\sim \sqrt{x_D^2 + y_D^2}/r_B^\pi$.
Correct for this affect by using mode-specific time acceptance.
Must additionally consider CP violation (e.g. [EPJC 73 (2013) 2476]).

From Run 1 to Run 2

Further Run 1 exploitation

Further sensitivity can be obtained from the Run 1 data set.
Update values of modes with 1 fb^{-1} analysis:

- $B^{\pm} \to D(h^{+}h^{-})K^{\pm}$ ADS/GLW
- $B^{\pm} \to D(K^{\pm}\pi^{\mp}\pi^{+}\pi^{-})K^{\pm}$
- $B_s^0 \to D_s K$

Anticipate 6–10° precision when everything is updated to 3 fb^{-1}.
Additional modes being investigated:

- $B^{\pm} \to D(h^{+}h^{-}\pi^{0})K^{\pm}$
  - $D^0 \to \pi^{+}\pi^{-}\pi^{0}$ CP+ content 97%; paper posted today [hep-ex/1410.3964]
- $B^{\pm} \to D(X)K^{\pm}h^{+}h^{-}$
- $B^{\pm} \to D^{*}\{D^0\gamma, D^0\pi^0\}K^{\pm}$
- Amplitude analyses ($B^0 \to D^0K^{\pm}\pi^{\mp}$, 4-body D^0 decays)
- etc...

Will also be exploited in Run 2.

Important systematic uncertainties

In general measurements are statistically limited.

Several systematics anticipated to become important for Run 2/upgrade:

- Production and detection asymmetries
  - Active LHCb program to measure precisely
- Particle ID
  - Improvements in calibration procedure
- Dalitz plot acceptance
  - Model with control channels
- MC-data differences
  - Particularly L0 hardware trigger — to be removed in upgrade
- External parameters
  - Charm factory inputs. CLEO-c → BES-III
  - Γ_s, $\Delta\Gamma_s$ for $B_s^0 \to D_s K$ } LHCb measurements
  - Fragmentation fractions f_s/f_d } LHCb measurements
- Flavour tagging

K^0 mixing, CPV and matter interactions

Final states containing K_S^0 also susceptible to biases due to K^0–$\bar{K}^0$ mixing and CPV [JHEP 1403 (2014) 008].

Estimated bias on $\gamma \sim |\varepsilon_K / r_B| \sim 1^\circ$

- As with D^0 mixing, more significant for $B^\pm \to D\pi^\pm$ measurements
- Will become important for $B^\pm \to DK^\pm$ in upgrade era.

In addition the neutral kaon system undergoes additional mixing due to different nuclear interaction cross sections.

Considered in LHCb semileptonic ΔA_{CP} study [JHEP 07 (2014) 041].

Influence of matter interactions $\approx$ that of mixing and CPV.

Run 2 data set

Run 2 will commence in June 2015.
Anticipate $\sim 6\ \text{fb}^{-1}$ of data: double that collected in Run 1.
Assuming $\sigma(b\bar{b}) \propto \sqrt{s}$, will be $1.6\times$ higher at 13 TeV compared to 8 TeV $\rightarrow$ 3–4 $\times$ the amount of signal for each channel.
Lower pileup but larger track multiplicity; similar S/B expected.
Precision on $\gamma \sim 4^\circ$.

Main competitor is Belle II:

- Begins $\Upsilon(4S)$ run in 2017.
- Anticipate $4\ \text{ab}^{-1}$ in 2018 and $50\ \text{ab}^{-1}$ in total.
- Competitive with LHCb in $B^\pm$ and B^0 decays (but not B_s^0)
- Able to access CP-odd eigenstates ($K_S^0\pi^0$, $K_S^0\omega$, ...)

Conclusions

- LHCb has a very active program to measure γ
- World-leading precision: $\gamma \sim (72.9^{+9.2}_{-9.9})^{\circ}$ (frequentist, no $B^{\pm} \to D\pi^{\pm}$)
- Many analyses already published, and several to follow
- Still to exploit full Run 1 data set
- Run 2 precision expected $\sim 4^{\circ}$
- Upgrade expected $\lesssim 1^{\circ}$
- Several experimental and theoretical challenges along the way
- See also Vincenzo's talk on loop-level measurements of γ and Joachim's talk on γ theory

Backup

Model-independent γ with $B^{\pm} \to D(K^0_S h^+ h^-)K^{\pm}$

Yield of $B^{\pm}$ decays in each Dalitz plot bin:

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

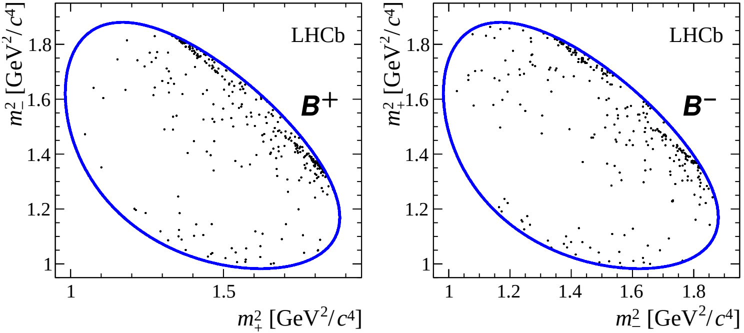
where

$$x_{\pm} \equiv r_B \cos(\delta_B \pm \gamma)$$
$$y_{\pm} \equiv r_B \sin(\delta_B \pm \gamma)$$

c_i and s_i are weighted cosine and sine of D^0 strong phase difference in each bin. Measured by CLEO-c [PRD 82 (2010) 112006].
K_i are D^0 decay yields in each bin. Measured using semileptonic B decays, correcting for efficiency and background.
$h_{B^{\pm}}$ are normalisation constants.

$K_S^0 K^+ K^-$ Dalitz plots

$K_S^0 K^+ K^-$ data ($\sim$ 420 candidates)

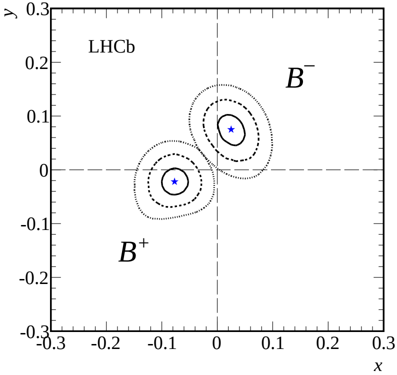


$m_\pm^2 \equiv m^2(K_S^0 K^\pm)$

Model-independent γ with $B^{\pm} \to D(K^0_S h^+ h^-)K^{\pm}$

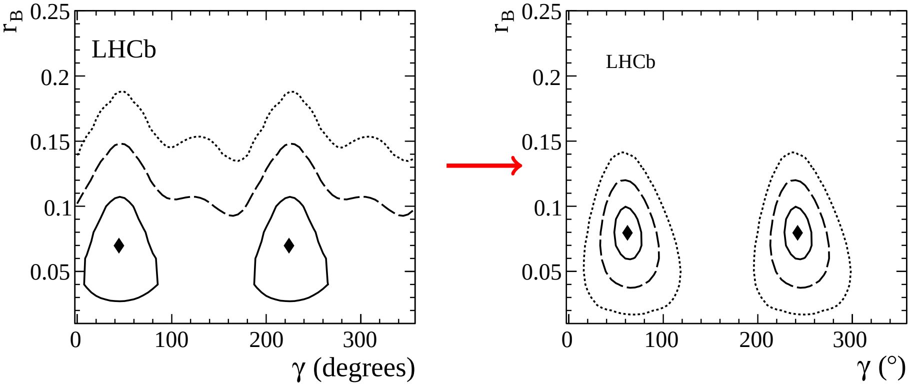
$$x_{\pm} \equiv r_B \cos(\delta_B \pm \gamma)$$
$$y_{\pm} \equiv r_B \sin(\delta_B \pm \gamma)$$

Two-dimensional confidence intervals:



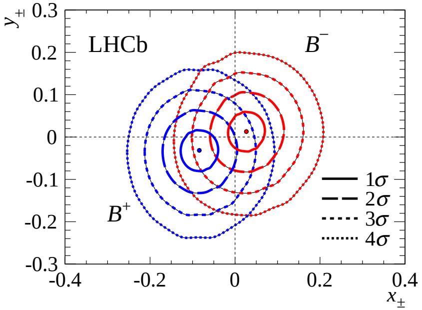
Model-independent γ with $B^{\pm} \to D(K^0_S h^+ h^-)K^{\pm}$

Moving from 1 fb^{-1} to 3 fb^{-1}



Model-dependent γ with $B^{\pm} \to D(K^0_S h^+ h^-)K^{\pm}$

Confidence intervals on $x_{\pm}$ and $y_{\pm}$:



CP observables in $B_s^0 \to D_s K$

$$C_f = \frac{1 - r_{D_sK}^2}{1 + r_{D_sK}^2} ,$$

$$A_f^{\Delta\Gamma} = \frac{-2 r_{D_sK} \cos(\delta - (\gamma - 2\beta_s))}{1 + r_{D_sK}^2} , \quad A_{\bar{f}}^{\Delta\Gamma} = \frac{-2 r_{D_sK} \cos(\delta + (\gamma - 2\beta_s))}{1 + r_{D_sK}^2} ,$$

$$S_f = \frac{2 r_{D_sK} \sin(\delta - (\gamma - 2\beta_s))}{1 + r_{D_sK}^2} , \quad S_{\bar{f}} = \frac{-2 r_{D_sK} \sin(\delta + (\gamma - 2\beta_s))}{1 + r_{D_sK}^2} .$$

Results:

$$\begin{aligned} C_f &= 0.53 \pm 0.25 \pm 0.04 , \\ A_f^{\Delta\Gamma} &= 0.37 \pm 0.42 \pm 0.20 , \\ A_{\bar{f}}^{\Delta\Gamma} &= 0.20 \pm 0.41 \pm 0.20 , \\ S_f &= -1.09 \pm 0.33 \pm 0.08 , \\ S_{\bar{f}} &= -0.36 \pm 0.34 \pm 0.08 , \end{aligned}$$

External input for h^+h^- modes

CLEO-c [PRD 86 (2012) 112001]

$$\cos\delta = 0.81^{+0.22}_{-0.18}{}^{+0.07}_{-0.05}$$

BES-III [PLB 734 (2014) 227]

$$\cos\delta = 1.02 \pm 0.11 \pm 0.06 \pm 0.01$$

External input for $K^0_S K\pi$ modes

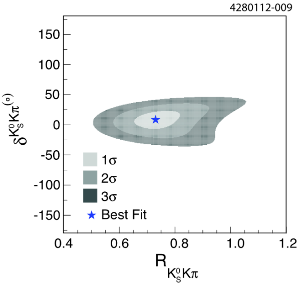
CLEO-c [PRD 85 (2012) 092016]

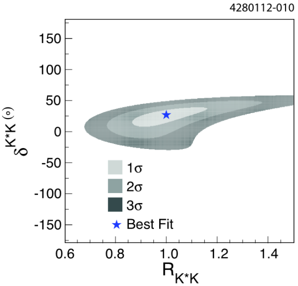
$$R_{K^0_S K\pi} = 0.73 \pm 0.08, \qquad \delta_{K^0_S K\pi} = (8.3 \pm 15.2)^\circ$$

In the region of the $K^*(892)^\pm$ mass

$$R_{K^* K} = 1.00 \pm 0.16, \qquad \delta_{K^* K} = (26.5 \pm 15.8)^\circ$$

→ High coherence



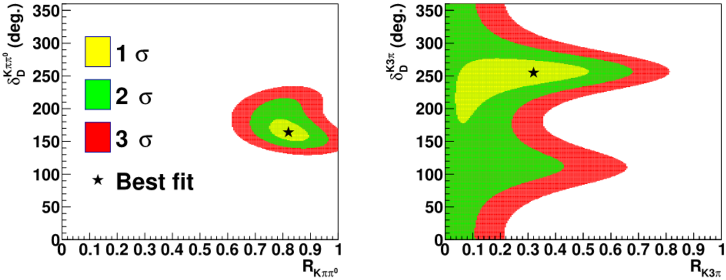


External input for $K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$, $K^{\pm}\pi^{\mp}\pi^{0}$ modes

CLEO-c [PRD 80 (2009) 031105], updated measurements [PLB 731C (2014) 197]

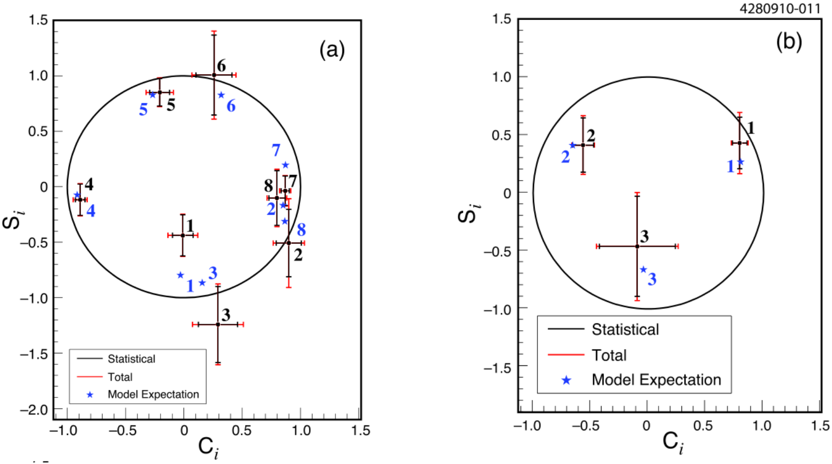
$$R_{K^{\pm}\pi^{\mp}\pi^{0}} = 0.82 \pm 0.07, \qquad \delta_{K^{\pm}\pi^{\mp}\pi^{0}} = (164^{+20}_{-14})^{\circ}$$

$$R_{K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}} = 0.32^{+0.20}_{-0.28}, \qquad \delta_{K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}} = (225^{+21}_{-78})^{\circ}$$



External input for $K_S^0 h^+ h^-$ modes

CLEO-c [PRD 82 (2010) 112006]

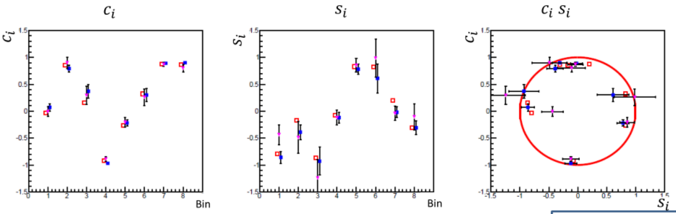


External input for $K_S^0 h^+ h^-$ modes

BES-III preliminary measurement. Slide from Roy Briere, CKM 2014 ([link]):

BESIII

New $K_S\pi^+\pi^-$ Results



Bins	c_i BES-III	c_i CLEO-c	s_i BES-III	s_i CLEO-c
1	0.066 ± 0.066	-0.009 ± 0.088	-0.843 ± 0.119	-0.438 ± 0.184
2	0.796 ± 0.061	0.900 ± 0.106	-0.357 ± 0.148	-0.490 ± 0.295
3	0.361 ± 0.125	0.292 ± 0.168	-0.962 ± 0.258	-1.243 ± 0.341
4	-0.985 ± 0.017	-0.890 ± 0.041	-0.090 ± 0.093	-0.119 ± 0.141
5	-0.278 ± 0.056	-0.208 ± 0.085	0.778 ± 0.092	0.853 ± 0.123
6	0.267 ± 0.119	0.258 ± 0.155	0.635 ± 0.293	0.984 ± 0.357
7	0.902 ± 0.017	0.869 ± 0.034	-0.018 ± 0.103	-0.041 ± 0.132
8	0.888 ± 0.036	0.798 ± 0.070	-0.301 ± 0.140	-0.107 ± 0.240

***Only statistical uncertainty is listed

BESIII Preliminary

Model prediction
BESIII
CLEO-c

Consistent agreement with CLEO-c measurements.

Improved errors w.r.t. CLEO-c

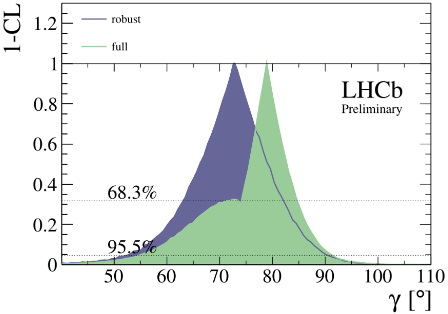
Source: *CLEO Collaboration, Physical Review D*, vol 82., pp. 112006 - 112035

Slide from Dan Ambrose, APS 2014

Sep 2014 Briere / CKM 2014 20

Full LHCb γ combination

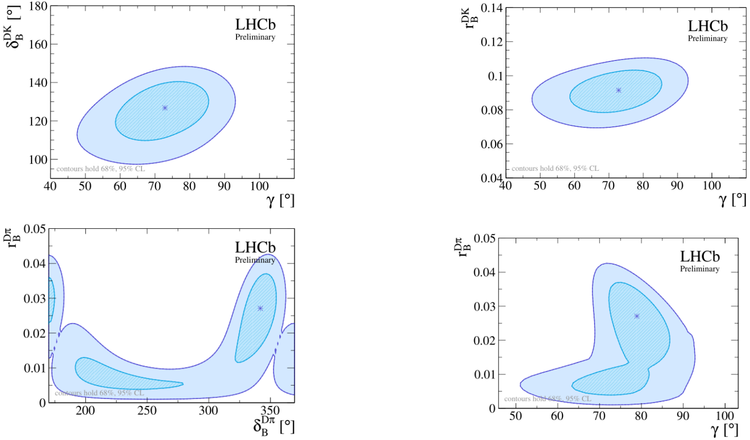
Full combination including $B^{\pm} \to D\pi^{\pm}$ decays.



$\gamma = 72.8^{\circ}, 78.9^{\circ}$ with 68% CI [71.5°, 84.7°]

LHCb γ combination

Two-dimensional confidence intervals on γ, r_B, δ_B.
Top row: $DK^{\pm}$ only; bottom row: including $D\pi^{\pm}$.



Expectation from previous workshop

Table 16: Statistical sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that which will be achieved by LHCb before the upgrade, and that which will be achieved with $50\,\mathrm{fb}^{-1}$ by the upgraded experiment. Systematic uncertainties are expected to be non-negligible for the most precisely measured quantities. Note that the current sensitivities do not include new results presented at ICHEP 2012 or CKM2012.

Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\ \phi$)	0.10 [138]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\ f_0(980)$)	0.17 [214]	0.045	0.014	~ 0.01
	a_{sl}^s	6.4×10^{-3} [43]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [43]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [67]	0.025	0.008	0.02
	$s_0\, A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [67]	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [76]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [85]	8 %	2.5 %	~ 10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [13]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–$12°$ [244, 258]	4°	0.9°	negligible
	γ ($B_s^0 \to D_sK$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\ K_S^0$)	0.8° [43]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [43]	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}	–

f_s/f_d

f_s/f_d is important input for many analyses measuring γ.

Hadronic measurement on 1 fb^{-1} [JHEP 04 (2013) 001], semileptonic measurement on 3 pb^{-1} [PRD 85 (2012) 032008], hadronic & semileptonic combination [LHCb-CONF-2013-011]. Hadronic 1.7% (stat), 9.6% (syst); semileptonic 3% (stat), $^{+7.1}_{-5.9}$ (syst).

Dominant uncertainty on hadronic measurement is due to theoretical uncertainties (form factors, SU(3) breaking — e.g. Fleischer, Serra and Tuning [Phys. Rev. D 82, 034038 (2010)]).

At least one group involved in reduction of uncertainties using lattice [PRD 85 (2012) 114502].