Status and prospects for γ at LHCb

6th LHCb Implications Workshop

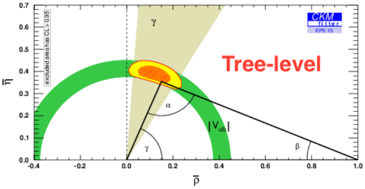
Dan Johnson
CERN

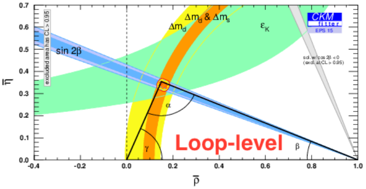
on behalf of the LHCb collaboration

13th October 2016

The CKM phase γ: constraining the UT

① More room for NP in loop processes





② Loop processes constrain the triangle apex more

- Least well-known angle is γ...
- ... can be determined at tree-level with tiny theory uncertainty JHEP 01 051

③ Direct measurements: $\gamma = 73.2^{+6.3\circ}_{-7.0}$ Indirectly: $\gamma = 66.9^{+0.94\circ}_{-3.44}$

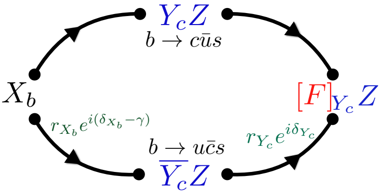
④ SM standard candle (assuming no NP at tree-level PRD 92(3) 033002)

Tree-level measurements of γ

Decay rates depend on γ for processes like:

$$X_b \rightarrow [F]_{Y_c} Z \qquad \text{(e.g. } B^{\pm} \rightarrow [K^{\mp}\pi^{\pm}]_D K^{\pm}\text{)}$$

- Final state F accessible to Y_c and $\overline{Y_c}$:
- $Z \in \{K, \pi, K^*...\}$



γ is the weak phase difference between decay amplitudes with $b \rightarrow c\bar{u}s$ and $b \rightarrow u\bar{c}s$ transitions

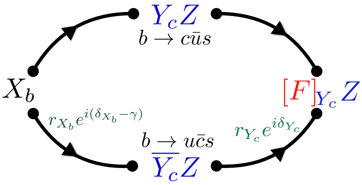
Tree-level measurements of γ

Decay rates depend on γ for processes like:

$$X_b \to [F]_{Y_c} Z$$

e.g.

X_b	$[F]_{Y_c}$	Z	
$B^\pm$	$[K\pi, K3\pi]_D$	K, π	Pseudo-flavour state, "ADS" PRL 78 3257
$B^\pm$	$[KK, \pi\pi, 4\pi]_D$	K, π	CP eigenstate, "(q)GLW" e.g. PLB 253 483
B^0	$[KK, \pi\pi]_D$	$K^-\pi^+$	B Dalitz analysis PRD 80 092002
B^0	$[K^0_\mathrm{S} h^+ h^-]_D$	K^{*0}	"GGSZ" PRD 63 036005



Aside from γ:

- r_B, δ_B (κ_B): B hadronic parameters vary
- r_D, δ_D: D hadronic parameters from CLEO
- D mixing corrections where necessary

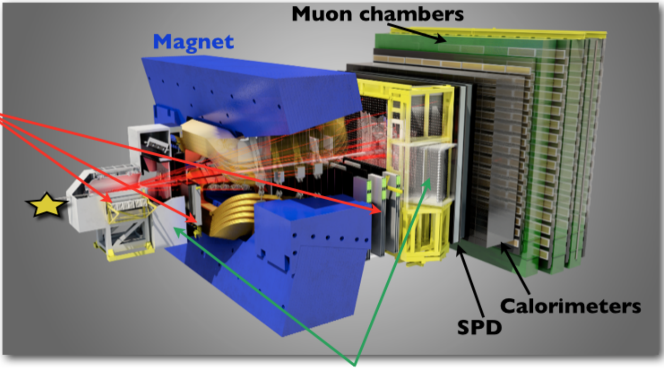
LHCb latest:

1. Selecting $B \to D$ decays at LHCb
2. An overview of new LHCb results:
    - $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$ PLB 760 117
    - $B^0 \to [K\pi, KK, \pi\pi]_D K\pi$ PRD 93 112018
    - $B^0 \to [K^0_S h^+ h^-]_D K^{*0}$ JHEP 1606 131
3. Putting it all together: γ from LHCb LHCb-CONF-2016-001

1) Selecting $B \to D$ decays at LHCb

Efficient hadronic trigger

- Hardware: Reduce 20 MHz crossing-rate to 1 MHz
- Software: Reduce to $\mathcal{O}(\,\mathrm{kHz})$ (high p_{T} track followed by multi-variate topological trigger)



Vertex Locator and tracking system:
B and D vertex positions and track momenta

IP resolution: 20μm
Δp/p: 0.4-0.6 %

RICH detectors:
K/π separation

Exploit:

- Topology: long B and D flight distances; large decay product impact parameter
- Kinematic: B momentum; high p_{T} solo-particle from B decay

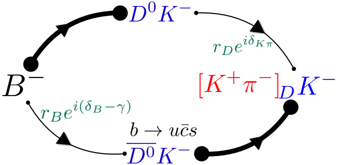
LHCb latest:

1. Selecting $B \to D$ decays at LHCb
2. An overview of new LHCb results:
   - $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$ PLB 760 117
   - $B^0 \to [K\pi, KK, \pi\pi]_D K\pi$ PRD 93 112018
   - $B^0 \to [K^0_S h^+ h^-]_D K^{*0}$ JHEP 1606 131
3. Putting it all together: γ from LHCb LHCb-CONF-2016-001

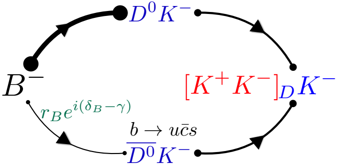
2.1) Case study: $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$

Typical decay rates with main sensitivity to γ

- $B^- \to [K^+\pi^-]_D K^-$
  - $\propto r_D^2 + r_B^2 + 2 r_B r_D^{K\pi} \cos(\delta_B + \delta_D^{K\pi} \mp \gamma)$
  - $r_B = (9 \pm 1)\%$; $r_D^{K\pi} = (5.91 \pm 0.03)\%$
  - Large interference



- $B^{\mp} \to [K^+K^-, \pi^+\pi^-]_D K^-$
  - $\propto 1 + r_B^2 + 2 r_B \cos(\delta_B \mp \gamma)$
  - Bigger rate; less interference



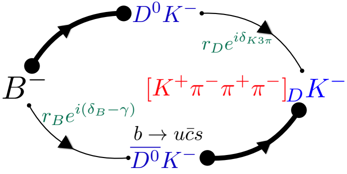
NB:

- Also study $D\pi$ system: expect $r_B^{\pi} \sim (0.5 - 1\%)$ → much less interference
- Fit for ratios and asymmetries

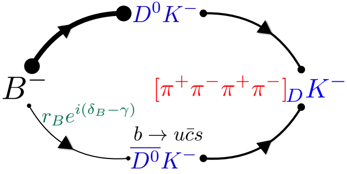
2.1) Case study: $B^\pm \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K,\pi\}$

Extending to four-body final states

- $B^- \to [K^+\pi^-\pi^+\pi^-]_D K^-$
  - Resonances in $D \to K3\pi \Rightarrow$ varying $\delta_D^{K3\pi}$
  - Dilution of interference parameterised by:
    - ★ Coherence factor $\kappa_D^{K3\pi} = 0.32 \pm 0.10$
    - ★ Ave. strong phase difference $\delta_D^{K3\pi}$
    - ★ PLB 757 520, PRL 116 241801
  - $\propto r_D^{K3\pi 2} + r_B^2 + 2\kappa_D^{K3\pi} r_B r_D^{K3\pi} \cos(\delta_B + \delta_D^{K3\pi} \mp \gamma)$

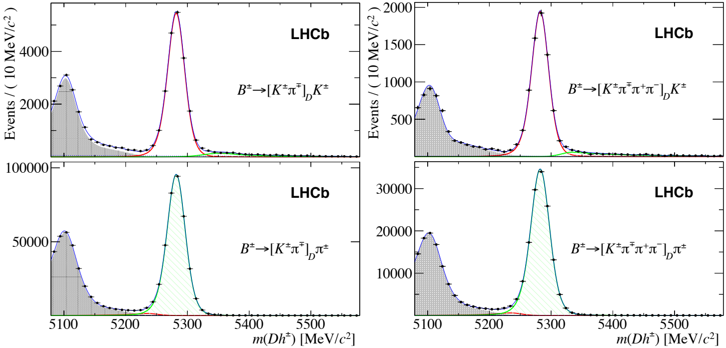


- $B^\mp \to [\pi^+\pi^-\pi^+\pi^-]_D K^-$
  - Dilution of interference due to resonances
    - ★ CP-even fraction $F_+^{4\pi} = 0.737 \pm 0.032$
    - ★ PLB 747 9
  - $\propto 1 + r_B^2 + 2(2F_+^{4\pi} - 1) r_B \cos(\delta_B \mp \gamma)$



2.1) Case study: $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$

Favoured mode



29,500±200 $B^{\pm} \to [K^{\pm}\pi^{\mp}]K^{\pm}$

11,300±100 $B^{\pm} \to [K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}]K^{\pm}$

378,100±100 $B^{\pm} \to [K^{\pm}\pi^{\mp}]\pi^{\pm}$

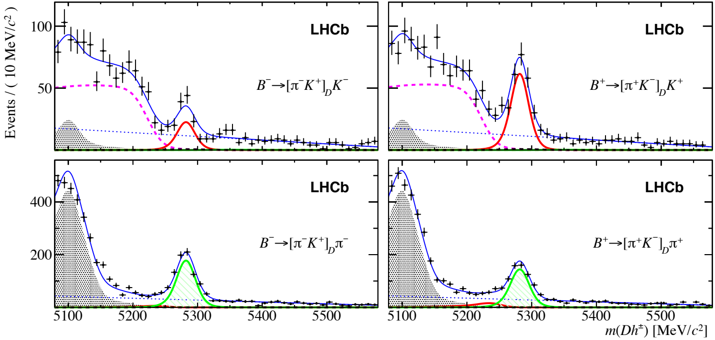
142,900±400 $B^{\pm} \to [K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}]\pi^{\pm}$

- Share aspects of the signal fit PDFs and constrain backgrounds
- $B^{\pm}$ production asymmetry : assume no interference in favoured decay mode
  - Small (0.2%) systematic estimated using current knowledge of γ, r_B^{π}
- Detection asymmetries : using charm calibration samples

2.1) Case study: $B^\pm \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$

2 body suppressed 'ADS' mode 8σ CPV

$550_{\pm 30}$ $B^\pm \to [\pi^\pm K^\mp]K^\pm$



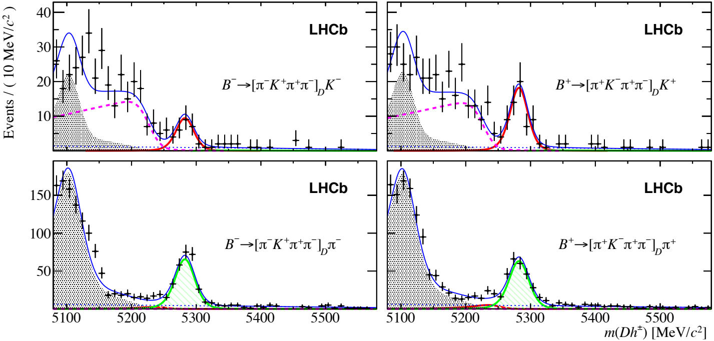
$1{,}360_{\pm 40}$ $B^\pm \to [\pi^\pm K^\mp]\pi^\pm$

- $A^{\pi K}_{ADS(K)} = -0.403 \pm 0.056 \pm 0.011$
  - First observation of CPV in a single $B \to Dh$ mode
- $A^{\pi K}_{ADS(\pi)} = 0.100 \pm 0.031 \pm 0.009$

2.1) Case study: $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$

4 body suppressed 'ADS' mode

160±20 $B^{\pm} \to [\pi^{\pm} K^{\mp} \pi^{+} \pi^{-}] K^{\pm}$



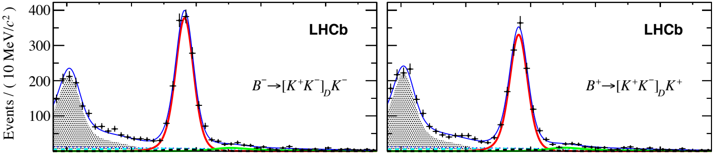
540±30 $B^{\pm} \to [\pi^{\pm} K^{\mp} \pi^{+} \pi^{-}] \pi^{\pm}$

- $A^{\pi K \pi\pi}_{ADS(K)} = -0.313 \pm 0.102 \pm 0.038$
  - Value of $\delta_D^{K3\pi} \Rightarrow$ expect same sign as $A^{\pi K}_{ADS(K)}$
- $A^{\pi K}_{ADS(\pi)} = 0.023 \pm 0.048 \pm 0.005$

2.1) Case study: $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$

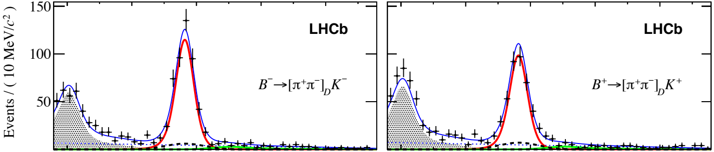
2 body 'GLW' modes 5σ CPV

3,800±90 $B^{\pm} \to [K^+K^-]K^{\pm}$



- $A^{KK}_{GLW(K)} = 0.087 \pm 0.020 \pm 0.008$

1,200±50 $B^{\pm} \to [\pi^+\pi^-]K^{\pm}$

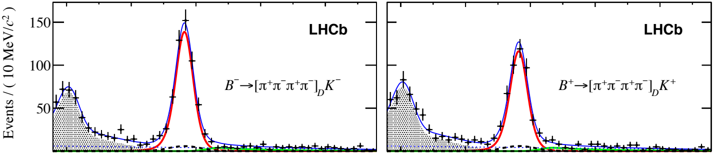


- $A^{\pi\pi}_{GLW(K)} = 0.128 \pm 0.037 \pm 0.012$

2.1) Case study: $B^{\pm} \rightarrow [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K,\pi\}$

Fits to the four-body 'quasi-GLW' mode

1,500±60 $B^{\pm} \rightarrow [\pi^+\pi^-\pi^+\pi^-]K^{\pm}$



- $A^{\pi\pi\pi\pi}_{ADS(\pi)} = 0.100 \pm 0.034 \pm 0.018$

- First time this mode has been analysed!
- Expect the asymmetry to be diluted by $\sim (2F_+^{4\pi} - 1)$ with respect to 2-body

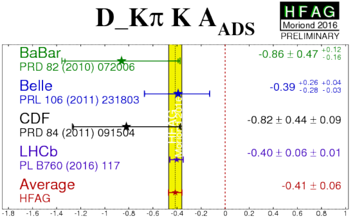
Remember:

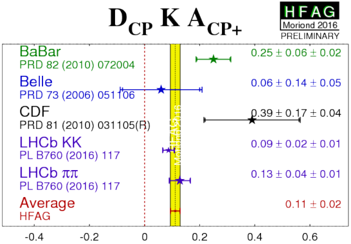
- $A^{KK}_{ADS(K)} = 0.087 \pm 0.020 \pm 0.008$
- $A^{\pi\pi}_{ADS(K)} = 0.128 \pm 0.037 \pm 0.012$

2.1) Case study: $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$

Conclusion

- Much greater precision in ‘ADS’ asymmetry measurements
- New measurements of ‘GLW’ asymmetries, adding the 4π mode





- Other observables compatible with expectation

LHCb latest:

1. Selecting $B \to D$ decays at LHCb
2. An overview of new LHCb results:
    - $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$ PLB 760 117
    - $B^0 \to [K\pi, KK, \pi\pi]_D K\pi$ PRD 93 112018
    - $B^0 \to [K^0_S h^+ h^-]_D K^{*0}$ JHEP 1606 131
3. Putting it all together: γ from LHCb LHCb-CONF-2016-001

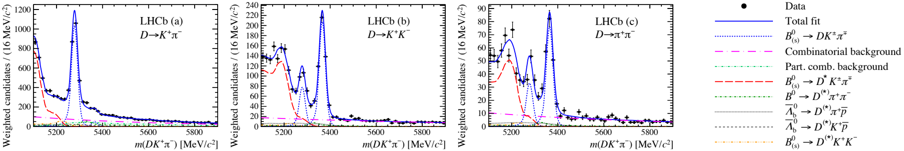
2.2) Case study: $B^0 \to [K\pi, KK, \pi\pi]_D K\pi$

Anticipate large CPV:

- For $B^+ \to DK^+$, $b \to u\bar{c}s$ is colour- and CKM-suppressed wrt $b \to c\bar{u}s$
- For $B^0 \to DK^{*0}$ (dominant), both $b \to$ ... amplitudes are colour-suppressed

Method:

- **Reconstruct** 1) $\bar{D}^0 \to K^+\pi^-$, 2) $D_{CP} \to K^+K^-$ and 3) $D_{CP} \to \pi^+\pi^-$
- Train **one neural network each** using $B^0 \to D\pi^+\pi^-$ data
- Use sidebands to **determine background models** and **efficiency variations** in the Dalitz plot for each bin of NN response
- Simultaneous fit of amplitude model (based on PRD 92 012012) to the three samples



2.2) Case study: $B^0 \to [K\pi, KK, \pi\pi]_D K\pi$

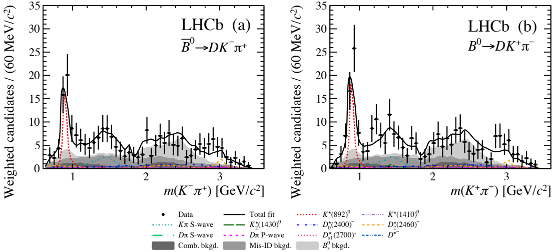
Dalitz fit:

- Divide the data into five bins of neural net response (discard the lowest)
- Total signal: 2,800 ($D \to K\pi$); 340 ($D \to KK$); 170 ($D \to \pi\pi$)
- For the favoured, $D \to K\pi$, mode, assume negligible interference in amplitude model:

$$\mathcal{A}\left(m^2(D\pi^-), m^2(K^+\pi^-)\right) = \sum_{j=1}^{N} c_j F_j\left(m^2(D\pi^-), m^2(K^+\pi^-)\right)$$

- For KK and $\pi\pi$ allow CP violation in $K\pi$ resonances:

$$c_j \longrightarrow \begin{cases} c_j & \text{for a } D\pi^- \text{ resonance}, \\ c_j\left[1 + x_{\pm,j} + i y_{\pm,j}\right] & \text{for a } K^+\pi^- \text{ resonance}, \end{cases}$$



Fit results

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

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

$x_+ = 0.04 \pm 0.16 \pm 0.11$

$x_- = -0.02 \pm 0.13 \pm 0.14$

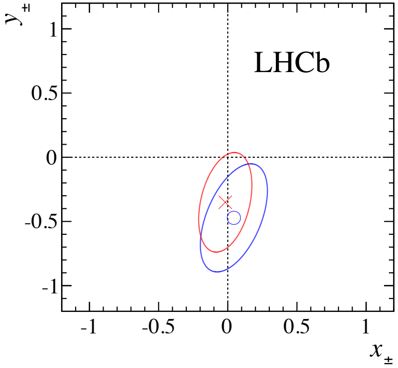
$y_+ = -0.47 \pm 0.28 \pm 0.22$

$y_- = -0.35 \pm 0.26 \pm 0.41$

2.2) Case study: $B^0 \to [K\pi, KK, \pi\pi]_D K\pi$

Conclusion

- Important new sensitivity; anticipating non-zero r_B
- Statistically unlucky this timen: no visible CP violation (x_+, y_+, x_-, y_-)



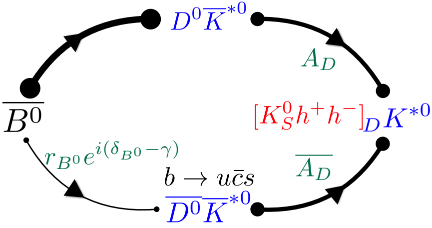
- Compute hadronic parameters for quasi-two-body analyses of $B \to DK^*(892)^0$:
  - Coherence factor: $\kappa = 0.958^{+0.005+0.002}_{-0.010-0.045}$
  - Relative magnitude: $\bar{r}_B / r_B = 1.02^{+0.03}_{-0.01} \pm 0.06$
  - Relative strong phase: $\bar{\delta_B} - \delta_B = 0.02^{+0.03}_{-0.02} \pm 0.11$

LHCb latest:

1. Selecting $B \to D$ decays at LHCb
2. An overview of new LHCb results:
   - $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$ PLB 760 117
   - $B^0 \to [K\pi, KK, \pi\pi]_D K\pi$ PRD 93 112018
   - $B^0 \to [K^0_{\mathrm{S}} h^+ h^-]_D K^{*0}$ JHEP 1606 131
3. Putting it all together: γ from LHCb LHCb-CONF-2016-001

2.3) Case study: $B^0 \to [K^0_S hh]_D K^{*0}$

Two new analyses of $B^0 \to DK^{*0}$ decays, using GGSZ method

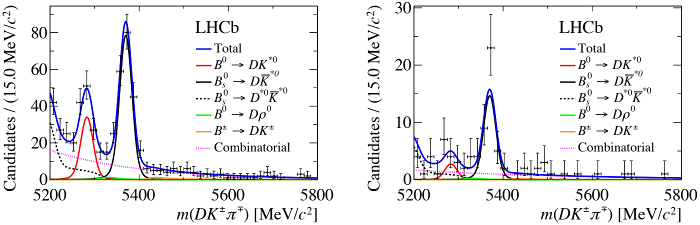


- Branching fraction is factor 20 lower than $B^\pm \to DK^\pm$
- $b \to c\bar{u}s$ & $b \to u\bar{c}s$ via internal-W $\Rightarrow r_{B^0} = 0.3 \Rightarrow$ more interference
- Resolves ambiguities in ADS/GLW analyses
- Two methods to handle D strong phase variation in Dalitz plot:
  - Model-independent: JHEP 06 131
    - Uses measured $\Delta\delta_D$ from CLEO in Dalitz regions
  - Model-dependent: JHEP 08 137
    - Amplitude model. Statistically optimal but model-related systematic uncertainties hard to define and determine

2.3) Case study: $B^0 \to [K^0_S hh]_D K^{*0}$

$B^0 \to DK^{*0}$ dataset:

- $\sim$80-90 candidates in $D \to K^0_S\pi^+\pi^-$
- $\sim$10 candidates in $D \to K^0_S K^+K^-$ (model-independent only)

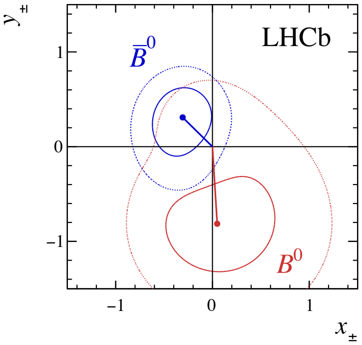


Analysis method in **Model-independent approach:**

- Compare distribution in bins of the Dalitz plot
- $N_i(B^0) \propto F_{\mp i} + (x_+^2 + y_+^2)F_{\pm i} + 2\kappa\sqrt{F_{+i}F_{-i}}(x_+ c_{\pm i} - y_+ s_{\pm i})$
  - Measure $x_{\pm} = r_B\cos(\delta_B \pm \gamma)$, $y_{\pm} = r_B\sin(\delta_B \pm \gamma)$)
  - Input CLEO measurements of average $\cos(\delta_D)$ and $\sin(\delta_D)$ at the $\psi(3770)$
  - $F_{\pm i}$ from flavour-tagged D decays
  - Employ coherence factor from $B^0 \to DK^+\pi^-$ amplitude analysis

2.3) Case study: $B^0 \to [K^0_S hh]_D K^{*0}$

Model-independent **results** (just 100 signal candidates!)



		stat.	syst.
x_+	=	0.05 ± 0.35	$\pm\, 0.02$
x_-	=	-0.31 ± 0.20	$\pm\, 0.04$
y_+	=	-0.81 ± 0.28	$\pm\, 0.06$
y_-	=	0.31 ± 0.21	$\pm\, 0.05$

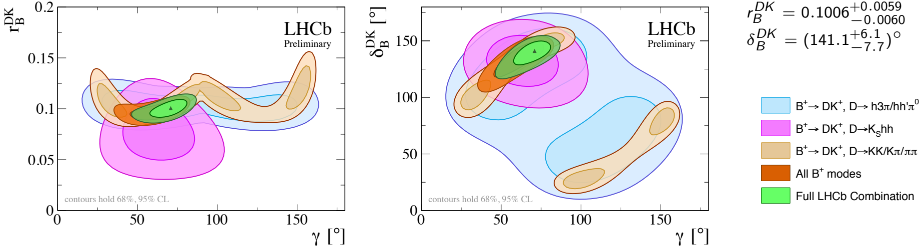
- Statistical uncertainty includes c_i and s_i (~ 0.02 for x and 0.05 for y)
- Model-dependent analysis gives compatible results

LHCb latest:

1. Selecting $B \to D$ decays at LHCb
2. An overview of new LHCb results:
    - $B^{\pm} \to [K\pi, K3\pi, KK, \pi\pi, 4\pi]_D\{K, \pi\}$ PLB 760 117
    - $B^0 \to [K\pi, KK, \pi\pi]_D K\pi$ PRD 93 112018
    - $B^0 \to [K^0_{\mathrm{S}} h^+ h^-]_D K^{*0}$ JHEP 1606 131
3. Putting it all together: γ from LHCb LHCb-CONF-2016-001

Putting it altogether: γ from LHCb

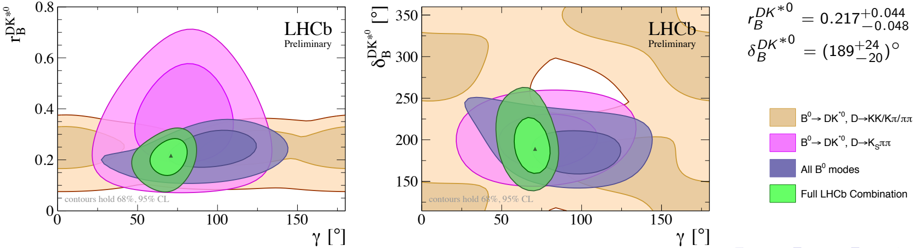
B^+ combination



$$r_B^{DK} = 0.1006^{+0.0059}_{-0.0060}$$

$$\delta_B^{DK} = (141.1^{+6.1}_{-7.7})^\circ$$

B^0 combination

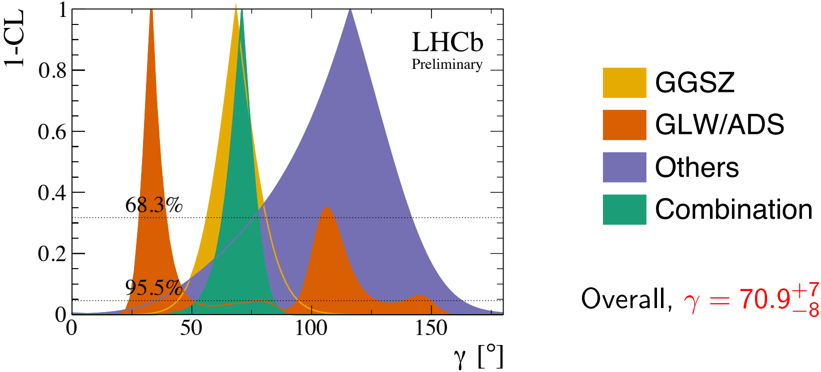


$$r_B^{DK^{*0}} = 0.217^{+0.044}_{-0.048}$$

$$\delta_B^{DK^{*0}} = (189^{+24}_{-20})^\circ$$

Putting it altogether: γ from LHCb

Result for γ



Overall, $\gamma = 70.9^{+7.1}_{-8.5}$

- Improves the previous LHCb-only determination by 2°
- Reaches Run 1 target sensitivity
- Good agreement with the B-factory results:
  - BaBar: $\gamma = (70 \pm 18)^\circ$
  - Belle: $\gamma = (73^{+13}_{-15})^\circ$

Outlook: continuing to exploit available data

Updated time-dependent analysis of $B_s^0 \to D_s K$ (full Run 1)

- Large interference effects expected at tree level; interesting to compare with time indep. analyses
- LHCb is the ideal place for this study:
  - Tripled int. lumi & improved selection with respect to our first analysis
  - High B_s^0 production rate in *pp*; efficient hadronic trigger
  - Excellent time resolution; strong flavour tagging capabilities
- Measures $\gamma - 2\beta_s$ and input precise measurement of β_s using $B_s^0 \to J/\psi\,\phi$ (penguin pollution $\Rightarrow \mathcal{O}(1^\circ)$)
- Future potential to instead constrain further β_s without penguin pollution uncertainties

Parallel analysis of $B^0 \to D^\pm \pi^\mp$ to measure $\gamma + 2\beta$ (full Run 1)

Outlook: continuing to exploit available data

Many complementary combinations of existing B and D modes still to be explored

1. New D modes:
   - $D \to KK\pi\pi$
   - $D \to K^0_{\mathrm{S}}\pi\pi\pi^0$
2. And new B modes:
   - $B \to D^* K$
   - $B \to DK^{*+}$
   - $B^0_s \to D^{*+}_s K$

$\Rightarrow$ **Investigations of all in progress**

Outlook: future data-taking

Assume that we will collect:

Sample	$\mathcal{L}$ (fb^{-1})	Units of Run-1
Run 1	3	1
Run 2	5	3
Upgrade	$\sim$50	$\sim$60
Future Upgrade	$\sim$300	$\sim$360

Run 2:

- Higher $\sigma_{\mathrm{prod}}(b\bar{b})$ (more than 2); better trigger & offline selection efficiency

(Future) Upgrade:

- Assume hadronic trigger efficiency $\sim$doubles
- Open up new potential sensitivity for γ e.g. $B_c^+ \to D_s^+ D_{\mathrm{CP}}$
  - Tree-level process with maximal CPV

Outlook: statistical and systematic uncertainties

Indirect γ precision is $^{+1.0\circ}_{-3.7}$. Will fall with lattice improvements
Therefore target sub-degree precision.

Reduction in statistical uncertainties

- Assume fall as $\frac{1}{\sqrt{N}}$ (i.e. by 2 in Run 2 and $\sim$8 ($\sim$19) in (future) upgrade)

Corresponding reduction in most systematic uncertainties

- Incorporate **physics corrections** (D mixing; K^0_S mixing, CPV, regeneration; ...)
- Reduction in uncertainty on **inputs**
- Further study of **backgrounds**
- General improvements in **methods**

For the *DK* combination:

- Some channels reach $\sigma(\gamma) \sim 1^\circ$; compare channels
- LHCb and Belle II precision similar in the Upgrade period

Sample	$\sigma_\mathrm{stat}(\gamma)^\circ$
Run 1	8
Run 2	4
Upgrade	~ 1
Future upgrade	<0.5

Limiting factors in the high-statistics era

Where will we become limited, as things stand:

- Most[1] $B \to DK$ modes rely on CLEO strong phase measurements at the $\psi(3770)$
- Allows for model independence; crucial in the high-statistics era
- Current systematic due to CLEO inputs $\sim 2^\circ$
- Some D modes not analysed by CLEO; some would benefit from D-phasespace-binned analysis

Available now:

- Quadruplication of the CLEO dataset at BES III ($\to$ systematic $\sim 1^\circ$)
  - Measurement in $D \to K\pi$ (Int.J.Mod.Phys.Conf.Ser. 31 1460305)
  - Preliminary results in $D \to K^0_\mathrm{S}\pi\pi$
- Supplement (but not match) with strong phase measurements in charm mixing

To avoid systematic limitation in the upgrade era:

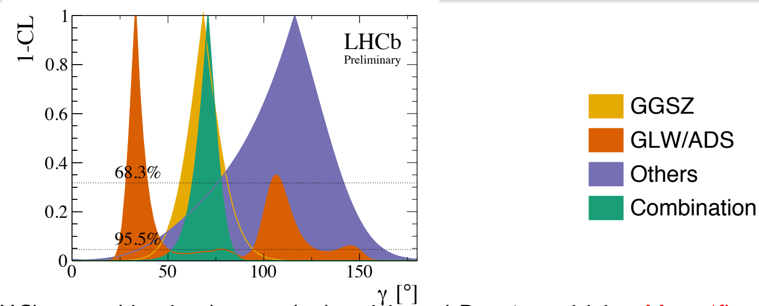
- Full spectrum of strong phase measurements with full 15-20 fb^{-1} at BES III

---

[1] not, e.g., $B^0_s \to D^+_s K$

Summary

$$\gamma_{\mathrm{LHCb}} = 70.9^{+7.1}_{-8.5}$$



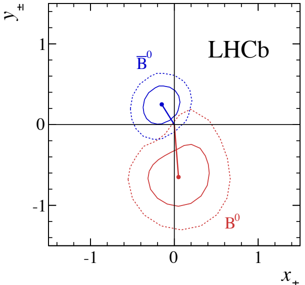
- LHCb γ combination has reached anticipated Run 1 sensitivity. Many 'firsts' in B and D modes
- Will rely on exploitation of the full BES III potential to avoid syst. limitation in the LHCb upgrade
- Already surpassed Run 1 dataset in most channels. Exciting first analyses with Run 2 data imminent
  - (we'd hope for new material at CKM; watch this space!)

Backup material

$B^0 \to DK^{*0}$: model-independent & dependent results

Results: good compatability

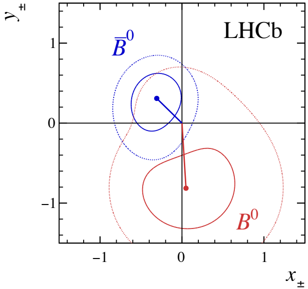
Model-dependent



$$\begin{aligned} x_+ &= 0.05 \pm 0.24 \pm 0.04 \pm 0.01 \\ x_- &= -0.15 \pm 0.14 \pm 0.03 \pm 0.01 \\ y_+ &= -0.65^{+0.24}_{-0.33} \pm 0.08 \pm 0.01 \\ y_- &= 0.25 \pm 0.15 \pm 0.06 \pm 0.01 \end{aligned}$$

Last column is estimated model uncertainty

Model-independent



$$\begin{aligned} x_+ &= 0.05 \pm 0.35 \pm 0.02 \\ x_- &= -0.31 \pm 0.20 \pm 0.04 \\ y_+ &= -0.81 \pm 0.28 \pm 0.06 \\ y_- &= 0.31 \pm 0.21 \pm 0.05 \end{aligned}$$

Statistical uncertainty includes c_i and s_i (~ 0.02 for x and 0.05 for y)

Other LHCb tree-level measurements of γ

Many more modes studied:

1. $B^{\pm} \to [K_{\mathrm{S}}^{0} h^{\pm} h^{\mp}]_D \{K, \pi\}$ ("GGSZ")
   - γ changes distribution of points in the D Dalitz plot
   - Efficiency comes from $B^0 \to D^{*\pm} \mu^{\mp} \nu_{\mu}$
   - CP (e.g. $D \to K_{\mathrm{S}}^{0} \rho$) and pseudo-flavour (e.g. $D \to K^{*-} \pi^{+}$) resolves ambiguities in ADS/GLW analyses
   - δ_D depends on D Dalitz position, measured with $\psi(3770) \to D^0 \overline{D}^0$ by CLEO
2. $B^{\pm} \to [K_{\mathrm{S}}^{0} K^{\mp} \pi^{\pm}]_D \{K, \pi\}$ ("GLS")
   - Use $D \to K^{*\pm} K^{\mp}$ Dalitz region
   - Coherence factor, ave. δ_D and D BF ratio from CLEO
3. $B^{\pm} \to [h^{+} h^{-} \pi^{0}]_D \{K, \pi\}$ ("quasi-GLW")
   - Challenge at LHCb to reconstruct the neutral π^0
   - Find CP fraction of decay at CLEO
4. $B^{\pm} \to [K^{\mp} \pi^{\pm} \pi^{0}]_D \{K, \pi\}$ ("ADS")
   - Coherence factor, ave. δ_D and D BF ratio from CLEO
5. $B^{\pm} \to [hh]_D K \pi \pi$ ("ADS")
6. $B_s^0 \to D_s^{+} K$, time dependent
   - Interference between mixed and unmixed B_s^0
   - Large interference effects

Putting it altogether: γ from LHCb

Previous result: CKM 2014 LHCb-CONF-2014-004

Included inputs from:

"ADS/GLW"

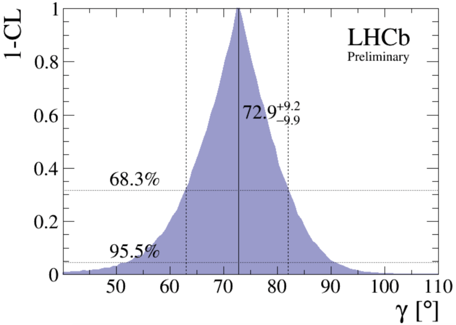
- $B \to Dh, D \to hh$ (2011) PLB 712 203
- $B \to DK\pi\pi, D \to hh$ PRD 92 112005
- $B \to DK^*, D \to hh$ PRD 90 112002
- $B \to DK, D \to K^0_S K\pi$ PLB 733 36

"GGSZ"

- $B \to DK, D \to K^0_S hh$ JHEP 10 097 (model-independent)

Time-dependent

- $B^0_s \to D^\mp_s K^\pm, D^+_s \to hhh^\mp$ JHEP 11 060 (time-dependent)



External

- Charm mixing and CPV parameters
- Relative magnitudes/strong phases, coherence factors
- B^0_s mixing

Putting it altogether: γ from LHCb

New combination: Moriond 2016 LHCb-CONF-2016-001

Additional inputs from:

"ADS/GLW"

- $B^{\pm} \to DK^{\pm}, D \to hh$ (full Run 1) PLB 760 117
- $B^{\pm} \to DK^{\pm}, D \to h\pi^{-}\pi^{+}\pi^{-}$ (ADS/quasi-GLW) PLB 760 117
- $B^{\pm} \to DK^{\pm}, D \to h\pi^{-}\pi^{0}$ (ADS/quasi-GLW) PRD 91 112014
- $B^{0} \to DK^{+}\pi^{-}, D \to hh$ (GLW Dalitz) PRD 93 112018

"GGSZ"

- $B \to DK^{*0}, D \to K^{0}_{\mathrm{S}}\pi^{+}\pi^{-}$ (model-dependent) JHEP 08 137

NB:

- Nominal method is plugin
- Uncertainties on external inputs included
- Exclude unphysical regions
- Bayesian cross-check carried out

Additional external inputs

- Charm rel. magnitudes/strong phases, coherence factors
- $B \to DK\pi$ rel. magnitudes/strong phases, coherence factors