# **SIN** Measurement of the CKM angle  $\gamma$

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MIAPP, Germany

**CERN Graphic Charter:** use of the outline version of the CERN logo

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 $\alpha$ 



#### Introduction <sup>20</sup> supressed to favoured decay amplitudes is related to and the hadronic parameters *<sup>B</sup>* ) <sup>21</sup> . It is often convenient to use a cartesian paramterisation; <sup>22</sup> *<sup>B</sup> ±* ). The precision with which can be measured **B ) 21 . It is often convenient to use a cartesian parameterisation;** a cartesian parameterisation; a cartesian p<br>In the cartesian parameterisation; a cartesian parameterisation; a cartesian parameterisation; a cartesian

• Why are we still measuring  $\gamma$ ? is inversely proportional to the value of *r<sup>X</sup>*  $\bullet$  Why are we still measuring  $\gamma$ ? In the *B*<sup>+</sup> ! *D*⇡<sup>+</sup> channel, *r<sup>D</sup>*⇡ • Why are we still measuring  $\gamma$ ?

<sup>20</sup> supressed to favoured decay amplitudes is related to and the hadronic parameters

- Least well known angle of the CKM unitarity triangle **B** virty are we suit incasuring the community of  $\cdot$  least well known angle of the CKM unitarity triangle
- Tree-level determination and extremely clean (theoretically) <sup>2</sup> Least well known angle of the Crywr unitality thangle<br>• Tree-level determination and extremely clean (theoretically) *V* I ree-level determination and extremely clean (theoretically)<br>• I oon-level access to look for NP • Tree-level determination and extre
- Loop-level access to look for NP • Loop-level access to look for NP

$$
\gamma = (73.2^{+6.3}_{-7.0})^{\circ}
$$
 [CKM filter]  

$$
\gamma = (68.3 \pm 7.5)^{\circ}
$$
 [UT fit]  

$$
I^{1.0}
$$

- Whats new from LHCb?  $\frac{3}{2}$  The latest combination of LHCb trees the latest combined measurements that  $\frac{3}{2}$ 
	-
- $\frac{1}{3}$  are sensitive to  $\frac{1}{3}$  are  $\frac{1}{3}$ ,  $\frac{1}{3}$ ,  $\frac{1}{3}$ ,  $\frac{1}{3}$ ,  $\frac{1}{2}$ 32 Spaat word more decay channels and updated channels and updated channels selected channels to the full run in 1 dataset in
- New combination  $\overline{3}$  rew combinations are performed.



<sup>19</sup> determined, where *X* is a specific final state of a *B* meson decay. The ratio of the

### **Detector**

- Its all in the name  $-$  beauty at the  $LHC$ 
	- During Run I we collected  $3f b^{-1}$
	- Run II at 13TeV more events per  $fb^{-1}$

Excellent tracking and vertex resolution

 $K\pi$  separation Particle ID for



Exploit B and D meson flight distance to suppress backgrounds

#### 10/11/2016

# How to measure  $\gamma$



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### New results from LHCb

- Several new or updated inputs into the combination
	- Two body GLW/ADS [M. Gronau, D. Wyler, Phys. Lett. B265 (1991) 172] [M. Gronau, D. London, Phys. Lett. B253 (1991) 483]

$$
B^{\pm} \to D K^{\pm}, D \to h^{+} h^{'-}
$$

• Four body GLW/ADS [D. Atwood, I. Dunietz, and A. Soni, Phys. Rev. Lett. 78 (1997) 3257, Phys. Rev. D63 (2001) 036005]

$$
B^{\pm} \to D K^{\pm} , D \to h^+ \pi^- \pi^+ \pi^-
$$

• GGSZ [A. Giri, Y. Grossman, A. Soffer, and J. Zupan, Phys. Rev. D68 (2003) 054018]

$$
B^0\to D K^{*0}\,, D\to K^0_S\pi^+\pi^-
$$

• GLW-Dalitz

[T. Gershon, Phys. Rev. D79 (2009) 051301] [T. Gershon, M. Williams, Phys. Rev. D80 (2009) 092002]

$$
B^0 \to D K^+ \pi^- \,, D \to h^+ h^-
$$

### New results from LHCb

• Several new or updated inputs into the combination

• Four body GLW/ADS  $\frac{1}{2}$  Update of LHCb<sup>2</sup>  $\sqrt{2}$  combination<sup>2</sup>  $B\rightarrow DK$  like decays  $^+\pi^-\pi^+\pi^$ and all  $\boldsymbol{B} \rightarrow D\boldsymbol{h}$  decays  $\frac{0}{S}\pi^+\pi^$ of  $B \to D K$  like decays

• Several new or updated inputs into the combination • Two body GLW/ADS • Four body GLW/ADS • GGSZ • GLW-Dalitz  $B^{\pm} \rightarrow DK^{\pm}$ ,  $D \rightarrow h^{+}h^{--}$  $B^{\pm} \rightarrow DK^{\pm}$ ,  $D \rightarrow h^+\pi^-\pi^+\pi^ B^0 \rightarrow D K^{*0}$  ,  $D \rightarrow K^0_S \pi^+ \pi^ B^0 \rightarrow D K^+ \pi^-$  ,  $D \rightarrow h^+ h^-$ 

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#### Two and four body GLW/ADS diagrams, *i.e.* there are no loops with virtual contributions from heavier particles so there is unclear to be an included to be an included the SM. However, the SM. However, the SM. However, the SM

angle can also be measured using processes containing processes containing loops, and any di $\alpha$ 

- Look at  $B \to Dh$  decays.<br> **But the using the set of the** 
	- GLW:  $D \to K^+K^-, \pi^+\pi^-, 2\pi^+2\pi^-$
- ADS:  $D \to K^+\pi^-, \pi^+K^-, K^+\pi^-\pi^+\pi^-, \pi^+K^-\pi^+\pi^-$



- Share signal shape parameters between 2(4) body modes Figure 2.4: Feynman diagrams for (left) *<sup>B</sup>*<sup>+</sup> ! *<sup>D</sup>*<sup>0</sup>*K*<sup>+</sup> and (right) *<sup>B</sup>*<sup>+</sup> ! *<sup>D</sup>*<sup>0</sup>*K*<sup>+</sup> decays.
- Constrain crossfeed between  $DK$  and  $D\pi$  modes (PID)
- Use  $D\pi$  as a control mode; charmless background etc angle . The amplitudes of the decays *<sup>B</sup>*<sup>+</sup> ! *<sup>D</sup>*0*K*<sup>+</sup> and *<sup>B</sup>*<sup>+</sup> ! *<sup>D</sup>*0*K*<sup>+</sup> (for which decay

#### Table 1: Signal yields as ADS favoured signals Table 1: Signal  $\mathcal{S}$  ,  $\mathcal{S}$  as measured in the B $\mathcal{S}$  -  $\mathcal{S}$   $\mathcal{S}$  ted signals and the state of the  $\blacksquare$  and national management  $\mathbf{E} = \mathbf{E} \mathbf{E} \mathbf{E} \mathbf{E} \mathbf{E}$ <sup>D</sup> K<sup>±</sup> 1162 ± 48 D = 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 red signals and the state of  $\sim$  $1$   $1$   $1$   $1$   $1$   $1$   $1$   $1$   $1$   $1$

 $\overline{\phantom{a}}$ 

 $\mathbf{E} = \mathbf{E} \mathbf{E}$ 

#### • Mass fits for the favoured modes  $\cdot$  Meso fits for the foucured modes.  $\overline{\text{must}}$  $n$   $\alpha$   $\beta$



<sub>-</sub>ow compinatorial background and tiny cross-feed contributions  $\overline{\phantom{0}}$ 9 Low combinatorial background and tiny cross-feed contributions

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invariant mass fits, together with their statistical uncertainties.

<sup>D</sup> K<sup>±</sup> 29,470 ± 230

<sup>D</sup> K<sup>±</sup> 29,470 ± 230

 $\mathcal{L} = \mathcal{L} \times \mathcal{L} = \mathcal$ 

by charge. See the caption of Fig. 1 for the definitions.

#### 2 body ADS suppressed signals  $\mathbf{B}=\mathbf{B}+\mathbf{$ <sup>D</sup> K<sup>±</sup> 3816 ± 92 ppropocal pigridio D K± 29,470 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 ± 2300 nnressed signals ppi voova orginalo 200V ALIS SHDDIASSAN SIND PID 37 43 1 2 1 1 0 0 1 Bkg 63 28 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 38 40 3

percentage of the statistical uncertainty on the observable. See the Table 2 caption for definitions.

 $\mathbb{E} \left[ \begin{smallmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{smallmatrix} \right]$ 

• Visible CP violation



<u>D π± 50,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,140 ± 270,</u>

<sup>D</sup> π<sup>±</sup> 378,050 ± 650

• Around 8 sigma!



 $\bar{f}_{\text{SUSY}} = -0.403 + 0.056 + 0.011$   $A_{\text{SUSY}}^{\pi K} = 0.100 + 0.031 + 0.031$  $\Delta_{\text{NS}(K)} = -0.403 \pm 0.056 \pm 0.011 \quad A_{\text{ADS}(\pi)}^{\pi K} = 0.100 \pm 0.031 \pm 0.009$  $A_{\text{ADS}(K)}^{\pi K}$  $= -0.403 \pm 0.056 \pm 0.011$ 

#### 10/11/2016  $\overline{5}$

#### 4 body ADS suppressed signals 4: DOOV ADS SUDDIESSEQ SIQNAIS by charge. See the caption of Fig. 1 for the definitions. and the first state of the first s nnressed signals ppı vuud organice  $\mathbf{E} = \mathbf{E} \mathbf$ <sup>D</sup> K<sup>±</sup> 11,330 ± 140 onressed signals ppropoca aignais

• Visible CP asymmetry

$$
B^{\pm} \to \left[\pi^{\pm} K^{\mp} \pi^{+} \pi^{-}\right]_{D} K^{\pm} \qquad 159 \pm 17
$$
  

$$
B^{\pm} \to \left[\pi^{\pm} K^{\mp} \pi^{+} \pi^{-}\right]_{D} \pi^{\pm} \qquad 539 \pm 26
$$

<sup>D</sup> π<sup>±</sup> 1360 ± 44

<u>D π± 142,910 ± 390,000 ± 390,0</u>

 $5100$   $5200$   $5200$   $5200$ 

• Close to 3 sigma evidence

 $5100$   $5200$   $5200$   $5200$ 



 $\frac{\pi K \pi \pi}{\text{ADS}(K)} = -0.313 \pm 0.102 \pm 0.038$   $A^{\pi K \pi \pi}_{\text{ADS}(\pi)} = 0.023 \pm 0.048 \pm 0.000$  $P(K)$  charge pink line is the signal peak shows partially reconstructed peak shows partially reconstructed peak shows partially reconstructed peak shows particles with  $P(K)$  $A_{\text{ADS}(K)}^{\pi K \pi \pi} = -0.313 \pm 0.102 \pm 0.038$   $A_{\text{ADS}(\pi)}^{\pi K \pi \pi} = 0.023 \pm 0.048 \pm 0.005$ 

#### 10/11/2016 for other definitions. B<sup>0</sup>

#### 2 body GLW modes Figure 3: Invariant mass distributions of selected B<sup>±</sup> → [π+π−]Dh<sup>±</sup> candidates, separated by charge. The dashed black line represents the residual contribution from charmless decays. This component is present in the D final states considered, but is most visible in this case. See the  $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$ **Example of 29,470 ± 230,470 ±**  $\mathbf{B} = \mathbf{A} \mathbf{A} \mathbf{A} + \mathbf{$ **LW modes** and the latter and the latter and the latter and the latter  $\sim$ E → FILO GOOD D K± 3816 ± 9216 ± 9216 ± 9216  $\blacksquare$  $\bf{H}$   $\bf{M}$   $\bf{L}$  29,470  $\bf{L}$  29,470  $\bf{L}$  2300  $\bf{L}$  $\textcolor{red}{\mathsf{L}}\mathsf{v}\mathsf{v}\ \ \textsf{modes}$  $\pm$   $\pm$   $\pm$ <sup>D</sup> K<sup>±</sup> 3816 ± 92 **Remain Reprise Reprise Remains Reserve ADS(π) ADS(π) And The American ADS(π) And The American American Addition** PID 37 43 1 2 1 1 0 0 1 5 Results

—<br>B± <del>(</del>K±π∓]

• Small asymmetries seen  $\frac{B^\pm\to [K^+K^-]_D\,K^\pm}{2}$  $K = 0.0004$   $\overline{B}$  or 0.0000  $\overline{B}$ 

 $\mathcal{L} = \mathcal{L} \times \mathcal{L}$ <sup>D</sup> π<sup>±</sup> 50,140 ± 270  $B^{\pm} \to [K^+K^-]$  $D K^{\pm}$  3816  $\pm$  92  $B^{\pm} \rightarrow [\pi^+\pi^-]$  $n K^{\pm}$  1162  $\pm$  48  $\mathbf{B}$  + [ $n+n-1$ ]  $D^{21}$  1162  $\pm$  18  $B^{\pm}$   $\overline{K^{\pm}}$  $V^{\pm}$  3816  $\pm$  02  $B^+ \to [K^+K^-]$  $1_D K^+$  3810  $\pm$  92  $B^{\pm} \to [\pi^+\pi^-]_D K^{\pm}$  $D K^{\pm}$  1162  $\pm$  48 B<sup>±</sup> → [π±K∓] 2 body GLW modes<br>• Small asymmetries seen  $\frac{B^{\pm} \rightarrow [K^+K^-]_D K^{\pm}}{B^{\pm} \rightarrow [K^+K^-]_D K^{\pm}} \qquad 3816 \pm 92$  $\overline{D}$  +  $\overline{L}$   $\over$  $K^{\pm}$   $3816 + 02$  $B^+ \to [K^+K^-]$  $D$  K<sup> $+$ </sup>  $3810 \pm 92$  $D^{\pm}$  →  $[*k*+*k*-]$  $\sqrt{1-K^{\pm}}$  3816 + 92  $B \rightarrow [N+1]$  $\frac{1}{D}$  A  $\frac{3010 \pm 32}{1162 + 48}$ Sim 160 0 0 0 0 1 0 0 0 SITIAN ASYMMICUTES SECTIFIED FOR  $B^{\pm} \rightarrow [\pi^+\pi^-]_D K^{\pm}$ The results of the fits to data, with statistical and systematic uncertainties, are: The results of the fits the fits to data, which shows  $\frac{1}{2}$ 

Decay mode Yield

Decay mode Yield

<u>D π± 50,140 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 270 ± 2</u>

.<br>D π± 378,050 ± 650,050 ± 650,050 ± 650,050 ± 650,050 ± 650,050 ± 650,050 ± 650,050 ± 650,050 ± 650,050 ± 650,

• About 5 sigma combined! 5100 5200 5400 5500 ) 2 *c*  $\mathcal{L} \subset \mathcal{L}$ 50 2000 200  $\bigcup_{i=1}^n \mathbb{O}(n)$ 150 <sup>−</sup> *KD* ] <sup>−</sup> π*<sup>+</sup>* →[π <sup>−</sup> *B* − π*D* ] − *K <sup>+</sup>* →[*K* <sup>−</sup> *B* **LHCb LHCb LHCb**  $5100$   $5200$   $5300$   $5400$   $5500$   $5500$ 50 100 150 *<sup>+</sup> KD* ]  $\mathcal{B} \rightarrow \mathcal{B}$ **LHCb LHCb LHCb**  $0.087 + 0.020 + 0.008$  $A^{\pi\pi}$  – 0.128 + 0.037 5100 5200 5300 5400 5500 ) 2 *c* ) 2 *c*  $\mathcal{L} \subset \mathcal{L}$ 100 200 300 100 400 <sup>−</sup> *KD* ] <sup>−</sup> *K+* →[*K* <sup>−</sup> *B* <sup>−</sup> *KD* ]*<sup>+</sup> K* <sup>−</sup> →[π <sup>−</sup> *B* **LHCb LHCb** 5100 5200 5300 5400 5500 100 200 300 400 *<sup>+</sup> KD* ] <sup>−</sup> *K+* →[*K <sup>+</sup> B* **LHCb** 5100 5200 5300 5400 5500 5100 5200 5300 5400 5500 20004000 6000 *<sup>+</sup>*π*<sup>D</sup>* − *K <sup>+</sup>* →[*K <sup>+</sup> B*  $F_{\chi}^{111}=0.087\pm 0.020\pm 0.008\quad A_{K}^{211}= 0.128\pm 0.037\pm 0.04$  $\blacksquare$  $\blacksquare$  $\blacksquare$  $\mathbf{A} = \mathbf{B} \mathbf{B}$  $\mathbf{H} = \mathbf{H} \mathbf{H} + \mathbf{H$  $\overline{1}$  and  $\overline{1}$  $\mathcal{F} = \mathcal{F} \mathcal{F} = \mathcal{F} \mathcal{F}$  $\mathcal{L} = \{1,2,3\}$  $\mathcal{F} = \{ \mathbf{r}_1, \ldots, \mathbf{r}_n \}$  $\blacksquare$ B<sup>±</sup> → [π+π−π+π−] d Katalunan dan Katalunan<br>Dan Katalunan dan Kataluna  $\blacksquare$  $\blacksquare$  . Then  $\blacksquare$  $\mathbf{F}_A$ <u>d K</u> 99<br>90 <sup>D</sup> π<sup>±</sup> 1360 ± 44  $\blacksquare$  $\blacksquare$  $\mathcal{F} = \mathcal{F} \mathcal{F}$  $\mathcal{L}$  $\mathbb{E} \mathbb{E} \left[ \begin{array}{cc} \mathbb{E} \mathbb{E} \mathbb{E} \left[ \begin{array}{cc} \mathbb{E} \mathbb{E} \mathbb{E} \left[ \mathbb{E} \mathbb{E} \mathbb{E} \left[ \mathbb{E} \mathbb{E} \right] \mathbb{E} \left[ \mathbb{E} \left[ \mathbb{E} \mathbb{E} \right] \right] \end{array} \right] \end{array} \right]$  $\sim$  11,330  $\pm$  $\mathcal{F} = \mathcal{F} \cup \mathcal{F}$  $\blacksquare$ B<sup>±</sup> → [π+π−π+π−] <u>d Katalandari (</u>  $\overline{\phantom{a}}$  ,  $\overline{\phantom{a}}$  $\overline{\phantom{a}}$  $\frac{1}{2}$  ,  $\frac{1}{2}$  ,  $\frac{1}{2}$  ,  $\frac{1}{2}$  ,  $\frac{1}{2}$  $\mathbf{E} = \mathbf{E} \mathbf{S} + \mathbf{S} \mathbf{S}$ B<sup>±</sup> → [K±π∓π+π−]  $\overline{\phantom{a}}$ , <mark>+ <sub>π</sub>+ π+π+</mark>  $\blacksquare$  $\blacksquare$  $\blacksquare$  $\mathbf{F} = \mathbf{F} \mathbf{F} \mathbf{F} + \mathbf{$  $\overline{D}$   $\overline{$  $\mathcal{F} = \mathcal{F}_k - \mathcal{F}_k$  $\blacksquare$ B<sup>±</sup> → [π±K∓] <u>d Kataluna dan Kataluna </u> anana aman'ny faritan'i Europa.<br>Bandara amin'ny faritan'i Europa amin'ny faritan'i Europa amin'ny faritan'i Europa amin'ny faritan'i Europa am  $\frac{1}{2}$  $\blacksquare$  $\mathcal{F} = \mathcal{F} \mathcal{F} = \mathcal{F} \mathcal{F}$  $D = 1/360$   $\pm 1/360$  $\mathcal{F} = \mathcal{F} \mathcal{F} = \mathcal{F} \mathcal{F}$  $\blacksquare$ <u> B± F≠Kr×</u> <u>d na 539  $\pm$  349  $\pm$  359  $\pm$  369  $\pm$  369  $\pm$ </u>  $\overline{a}$   $\overline{b}$   $\overline{b}$   $\overline{b}$   $\overline{b}$   $\overline{c}$   $\overline{$  $\mathbf{L}_{\mathbf{H}}$ 9 5100 5200 5300 5400 5500 Events / ( 10 MeV/ 5100 5200 5300 5400 5500 50 100 *<sup>+</sup> KD* ] <sup>−</sup> →[π*+K <sup>+</sup> B* **LHCb** 5100 5200 5300 5400 5500 ..<br>400 − π*D* ]*<sup>+</sup> K* <sup>−</sup> →[π <sup>−</sup> *B* ] 2 ) [MeV/*c* <sup>±</sup> *m*(*Dh* 5100 5200 5300 5400 5500 200 00 *<sup>+</sup>*π*<sup>D</sup>* ] <sup>−</sup> →[π*+K <sup>+</sup> B*  $K = 0.081 \pm 0.020 \pm 0.008$   $\Delta K = 0.120 \pm 0.091 \pm 0.05$  $R = \text{R}$ K = 0.087 ± 0.020 ± 0.021 ± 0.021 ± 0.021 ± 0.021 ± 0.021 ± 0.021 ± 0.021 ± 0.02 = −0.0145 ± 0.0050 ± 0.0050 ± 0.0050 ± 0.0050 ± 0.0050 ± 0.0050 ± 0.0050 ± 0.0050 ± 0.0050 ± 0.0050 ± 0.0050 ± RKK = 0.968 ± 0.022 ± 0.021 <u>K = 0.128  $+$ 0.128  $+$ 0128  $+$ <sup>π</sup> = 0.0043 ± 0.0086 ± 0.0031 Rππ = 1.002 ± 0.040 ± 0.026  $\mathcal{L} = \mathcal{L} \mathcal{L} = \mathcal{L} \mathcal{L} \mathcal{L} = \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} = \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} = \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} = \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} = \mathcal{L} \mathcal$ <u>ADS (K) = 0.00188 ± 0.00188 ± 0.00188 ± 0.00188 ± 0.00188 ± 0.0011 ± 0.0011 ± 0.0011 ± 0.0011 ± 0.0011 ± 0.001</u>  $AKK = \Omega R^2 + \Omega R^2 + \Omega R^2$  $\frac{44}{10}$   $\frac{0.001 \pm 0.020 \pm 0.000}{100}$ A<sup>K</sup><sup>π</sup> <sup>K</sup> = −0.0194 ± 0.0072 ± 0.0060 R<sup>K</sup><sup>π</sup>  $\frac{1}{\sqrt{2}}$  $\mathcal{L} = \{ \mathbf{0}, \$ AKK = −0.0145 ± 0.0050 ± 0.0017 <u>rak di partiti di par</u>  $\overline{\phantom{a}}$  $\frac{1}{2}$  and  $\frac{1}{2}$   $\frac{1}{2$  $\mathbf{m}$  and  $\mathbf{m}$  and  $\mathbf{m}$ Rππ = 1.002 ± 0.040 ± 0.026  $\mathbf{r}$  $\frac{1}{\sqrt{2}}$  ,  $\frac{1}{\sqrt{2}}$  $A^{\pi\pi} = 0.198 \pm 0.027 \pm 0.019$  $\frac{1}{K}$   $\frac{0.120 \pm 0.001 \pm 0.012}{1}$  $A_K^{KK} = 0.087 \pm 0.020 \pm 0.008$   $A_K^{\pi\pi}$  $\frac{\pi\pi}{K} = 0.128 \pm 0.037 \pm 0.012$ 

− π*D* ]

1000

feed is also included in the fit, but is too small to be seen. See the caption of Fig. 1 for other

<sup>−</sup> π*<sup>+</sup>* →[π <sup>−</sup> *B*

charge. The dashed cyan line represents particularly reconstructed Λ00 μ.Χ. το προσωπικό με το προσωπικό με το<br>Προσωπικό προσωπικό με το προσ

1000

Λ<sup>+</sup>

<sup>c</sup> <sup>h</sup><sup>−</sup> decays,

<sup>b</sup> → [p+K−π+]

#### 4 body GLW mode **DEAM ILIONE**  $\mathbf{B}=\mathbf{B}+\mathbf{$ <sup>D</sup> K<sup>±</sup> 1162 ± 48 GIW mode B<sup>±</sup> → [π±K∓] <sup>D</sup> K<sup>±</sup> 553 ± 34

 $\mathbf{E} = \mathbf{E} \mathbf$ 

 $\mathbf{E} = \mathbf{E} \cdot \mathbf{E} + \mathbf{E} \cdot \mathbf{E}$ 

• First use of this mode! • Decay ~75% CP even <sup>D</sup> π<sup>±</sup> 19,360 ± 150  $B^{\pm} \to [\pi^+\pi^-\pi^+\pi^-]$  $D K^{\pm}$  1497  $\pm$  60  $B^{\pm} \rightarrow [\pi^+\pi^-\pi^+\pi^-]$  $D \pi^{\pm}$  19,360  $\pm$  150  $\overline{K}$   $\overline{$  $L^+$   $1407 + 60$  $B^{\pm} \to \left[\pi^+\pi^-\pi^+\pi^-\right]_I$  $D K^+$  1497  $\pm$  60  $B^{\pm} \rightarrow [\pi^+\pi^-\pi^+\pi^-]$ 



by charge. The dashed black line represents the residual contribution from charmless decays.

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 $50.16$  for other definitions. The caption of  $\sim$ 

<sup>D</sup> K<sup>±</sup> 553 ± 34

• Several new or updated inputs into the combination • Two body GLW/ADS • Four body GLW/ADS • GGSZ • GLW-Dalitz  $B^\pm \to D K^\pm$  ,  $D \to h^+ h^{'-}$  $B^{\pm} \rightarrow DK^{\pm}$ ,  $D \rightarrow h^+\pi^-\pi^+\pi^ B^0 \to D K^{*0}$  ,  $D \to K_S^0 \pi^+ \pi^ B^0 \rightarrow DK^+\pi^-$ ,  $D \rightarrow h^+h^-$ 

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- Can also consider the neutral B channels
	- Decay chain  $B^0 \to D K^{*0}, D \to K^0_S \pi^+ \pi^-$
	- Yields lower than  $B^\pm \to D K^\pm$  but  $\boxed{r_{B^0}} \approx 3 r_B$
	- Model dependent uses model from BaBar (focus of this talk)
	- Model independent takes input from CLEO
		- Totally consistent results with comparable uncertainties



- **Table 1: Table 1: Table 1: Signal and Signal Strategy (model dependent)**
- First perform a fit to the B mass that in the invariant mass fit to the D mass
	- Candidates within the black lines used in the CP fit
	- Fit the D Dalitz plot with the BaBar model
	- Note we couldn't use the Belle model







4

#### $\mathbf{D}$   $\mathbf{p}_{\text{total}}$  $\mathcal{S}^{\circ}$  plots, shown as (a) the Dalitz plot, and its projections on  $\mathcal{S}^{\circ}$  $\mathcal{L}$ −, en<br>2002 - Co plots

 $\sim$  and (d) m2 and (d)  $\sim$ 

<sup>0</sup>. The line superimposed on the projections corresponds to the fit result and the points are data.

± *y*

- Model dependent results
- Extract cartesian parameters from CP fit • Extract cartesian parameters from GP interesting and the decay B0 → D(K0 + O(K0 is per-
	- No CPV at 2 sigma
- 3rd uncertainty from DP model a √ and 8 TeV by TeV violation at √s and 8 TeV violation at TeV violation and 8 TeV viola
- Stat uncertainties dominate to the  $\mathbb{R}$

$$
x_- = -0.15 \pm 0.14 \pm 0.03 \pm 0.01,
$$

$$
y_{-} = 0.25 \pm 0.15 \pm 0.06 \pm 0.01,
$$

$$
x_{+} = 0.05 \pm 0.24 \pm 0.04 \pm 0.01,
$$

 $y_+$  =  $-0.65 \frac{+0.24}{-0.23} \pm 0.08 \pm 0.01,$ 





<sup>−</sup>22)◦ and Figure 5: Likelihood contours at 68.3% and 95.5% confidence level for (x+, y+) (red) and (x−, y−) JHEP 08 (2016) 137

18

10/11/2016 precise measurements of the second to γ = (80+210) and the values. They correspond to  $\mu$  = (80+211) and to  $\mu$  = (80+211) and the values of the valu • Several new or updated inputs into the combination • Two body GLW/ADS • Four body GLW/ADS • GGSZ • GLW-Dalitz  $B^\pm \to D K^\pm$  ,  $D \to h^+ h^{'-}$  $B^{\pm} \rightarrow DK^{\pm}$ ,  $D \rightarrow h^+\pi^-\pi^+\pi^ B^0 \rightarrow D K^{*0}$  ,  $D \rightarrow K^0_S \pi^+ \pi^ B^0 \rightarrow DK^+\pi^-$ ,  $D \rightarrow h^+h^-$ 

#### 10/11/2016

#### GLW-Dalitz analysis from simulation based on known DP distributions [32–38] are used to model the partially reconstruction of signal decays. The fit signal decays in each  $\sim$ reconstructed and misidentified *B* decays. the correctly reconstructed *B*<sup>0</sup> *<sup>s</sup>* decays and misidentified backgrounds are taken to have reconstructed and misidentified *B* decays. The fraction of signal decays in each  $\sim$  10 output bin is allowed to vary free  $\sim$ the correctly reconstructed *B*<sup>0</sup>

from simulation based on known DP distributions [32–38] are used to model the partially

from simulation based on known DP distributions [32–38] are used to model the partially

- Measure  $\gamma$  using  $B^0 \to D K^+ \pi^-$  decays
- Use CP even modes • Use CP even modes  $D \to K^+K^-, \pi^+\pi^-$
- *c* 1000 1200 <sup>−</sup> π<sup>+</sup> *D*→*K* • Bin in output of the neural network 1200 UI N  $\frac{1}{\sqrt{2}}$  and  $\frac{1}{\sqrt{2}}$  in each  $\frac{1}{\sqrt{2}}$  of the variable to vary free  $\frac{1}{\sqrt{2}}$ .  $y_{(s)} \to D$ if iff output of the field field the fit of the fit of the fit misidentified backgrounds which are  $B_{(s)}^0 \to D K^{\pm} \pi^{\mp}$  $\sum_{i=1}^{n}$  are free parameters of the fit, except those for misidentified backgrounds which are  $\sum_{i=1}^{n}$  are  $\sum_{i=1}^{n}$  and  $\sum_{i=1}^{n}$  are  $\sum_{i=1}^{n}$  are  $\sum_{i=1}^{n}$  are  $\sum_{i=1}^{n}$  are  $\sum_{i=1}^{n}$  are  $\sum_{$ Construction relative to the signal yield, since the signal yields  $B_{(s)}^0 \rightarrow D K^{\pm} \pi^{\mp}$  $\sum_{i=1}^{n}$  are free parameters of the fit, except that is except that  $\sum_{i=1}^{n}$  are  $\sum_{i=1}^{n}$ Construction and relative to the signal yields  $B_{(s)}^0 \rightarrow D K^{\pm} \pi^{\mp}$
- Simultaneous DP fit  $\overline{\phantom{a}}$  and  $\overline{\phantom{a}}$

10/11/2016 )2 *c* 220

 $\frac{1}{\sqrt{2}}$ 

 $\begin{array}{ccc} \n\cdot & \cdot & \cdot \ 1 & \rightarrow & \cdot \end{array}$  $B^0_s \to D^{(*)} K^- \pi^+$  contributions  $\begin{array}{cc} \bar{\Lambda}^0_b \to D^{(*)} \pi^+ \bar{D}^0 \to$  $\mathbf{v}$ • Purity of the GLW modes hurt by Eff • Purity of the GLW modes hurt by  $\begin{array}{ccc} - & e^{(s)} \rightarrow D^{\star} K^{\pm} \pi^{\mp} \ \rightarrow & \rightarrow & D^{\star} K^{\pm} \pi^{\mp} \ \rightarrow & D^{(s)} \pi^{\pm} \pi^{\mp} \end{array}$ 

− *K*

Weighted candidates / (16 MeV/

<sup>+</sup> *D*→*K*



Figure 1: Results of fits to *DK*+⇡ candidates in the (a) *<sup>D</sup>* ! *<sup>K</sup>*+⇡, (b) *<sup>D</sup>* ! *<sup>K</sup>*+*K* and (c) Figure 1: Results of fits to *DK*+⇡ candidates in the (a) *<sup>D</sup>* ! *<sup>K</sup>*+⇡, (b) *<sup>D</sup>* ! *<sup>K</sup>*+*K* and (c) *<sup>D</sup>* ! ⇡+⇡ samples. The data and the fit results in each NN output bin have been weighted LHCb (c) fit is performed to the samples with di↵erent *D* decays by using the *J*fit method [41] as implemented in the Laura++ package [42]. The likelihood function contains signal as implemented in the Laura++ package [42]. The likelihood function contains signal Phys. Rev. D93 (2016) 112018 20<sup>−</sup> π<sup>+</sup> *D*→π

Data

pion; this is modelled with a non-parametric function. Non-parametric functions obtained

The fraction of signal decays in each  $N_{\rm N}$  in each  $N_{\rm N}$  in the fit; allowed to vary freely in the fit; allow

*<sup>s</sup>* decays and misidentified backgrounds are taken to have

Data rual iit<br>- ^

Total fit

 $B^0_{(s)} \to D K^{\pm} \pi^{\mp}$ 

 $B^0_{(s)} \to D^* K^{\pm} \pi^{\mp}$  $B^0 \to D^{(*)} \pi^+ \pi^ \overline{\Lambda}_{\underline{b}}^0 \rightarrow D^{(*)} \pi^+ \overline{p}$ 

Combinatorial background Combinatorial background Part. comb. background

#### GLW-Dalitz analysis + π <sup>−</sup> →*DK* <sup>0</sup> *B* GLW-L 12 − π <sup>+</sup> →*DK* <sup>0</sup> *B* **− Dalitz analysis** Figure 2: Dalitz plots for candidates in the *<sup>B</sup>* candidate mass signal region in the *<sup>D</sup>* ! *<sup>K</sup>*+*K* **Dalitz analysi** total 2840 **+**<sup>2</sup> *D* **70 signal decays in the** *D*  $\sim$  *K***<sup>+</sup> sample, while the corresponding values in the** for the *D* ! *K*<sup>+</sup>*K* and *D* ! ⇡<sup>+</sup>⇡ samples are 339 *±* 22 and 168 *±* 19. A more detailed breakdown of the fit results can be found in Ref.  $\bigcirc$  the fit results can be found in Ref. [40].  $\Box$ olity analysis describing the relative contribution for each intermediate contribution for each intermediate process, and the *F<sup>j</sup>* (*m*<sup>2</sup>(*D*⇡)*, m*<sup>2</sup>(*K*<sup>+</sup>⇡)) terms describe the resonant dynamics through the lineshape, angular distribution and barrier factors. The sum is over amplitudes from

 $\frac{1}{\sqrt{2}}$ 

) [GeV

<sup>2</sup>(2460), *K*⇤(892)<sup>0</sup>, *K*⇤(1410)<sup>0</sup> and *K*⇤

<sup>−</sup> →*DK* <sup>0</sup> *B*

• Amplitude fit based on previous results (see backups) Amplitude fit based or n provique roculte (con backune)  $S$  results (see backups). 5 10 15 20 ]4 /*c* <sup>2</sup> ) [GeV <sup>−</sup> *m*2(*D*<sup>π</sup> a Amplitude fit boood on provious requite (and hookung) and background terms in each  $\alpha$  in the results in  $\alpha$  $\mathbf{F}$   $\mathbf{F}$  $\overline{\sigma}$ n previous results (see backups)

<sup>0</sup>(2400), *D*⇤

• First time this method has been used and a both  $B$  and  $B$  and  $B$  and  $B$  candidates. Only candidates in the three purests  $B$ **e** First time this method has been used s Lies mule not the memory is the significant dependence significantly to the sensitivity and is supported to the sensitivity of the sensitivity of the sensitivity and is supported to the sensitivity of the sensitivity of constrained within uncertainties to known values [26, 31, 34, 43]. The values of the *c<sup>j</sup>* coecients are allowed to vary in the shape parameters of the shape parameters of the non-

) [GeV

the *D*⇤

each sample, where is the core width of the signal shape. In this region there are in

fit is performed to the samples with di↵erent *D* decays by using the *J*fit method [41]

- Use to  $D \to K^+ \pi^-$  help guide the fit no CPV allowed  $\log_{10} 11 \leq$  $\overline{u}$   $\overline{v}$   $\overline{v}$   $\overline{v}$   $\overline{v}$   $\overline{v}$   $\overline{v}$   $\overline{v}$   $\overline{v}$   $\overline{v}$ help quide the fit **10**  $\nu$  we d  $\pm$   $\pm$  belp quide the fit and CDV ellowed  $\pi$  . help guide the fit – ho CPV allowed is the combinatorial background; it is the subsequently in the subsequently  $\mathcal{L}$  $D \rightarrow K^+\pi^-$  help guide the fit – no CPV allowed
	- Include CPV for K\*(892) amplitude bility for  $K^*/(892)$  amplitude  $\sigma$ *z/* arripiitude

*K*π S-wave <sup>0</sup> \*(1430) *K*<sup>2</sup>

\n- Use to 
$$
D \to K^+\pi^-
$$
 help guide the fit – no CPV allowed
\n- Include CPV for  $K^*(892)$  amplitude
\n- $A(m^2(D\pi^-), m^2(K^+\pi^-)) = \sum_{j=1}^N c_j F_j(m^2(D\pi^-), m^2(K^+\pi^-))$   $c_j \longrightarrow \left\{ c_j \left[1 + x_{\pm,j} + iy_{\pm,j} \right] \right\}$  for a  $K^+\pi^-$  resonance
\n- S<sup>35</sup>olution
\n



<sup>−</sup> \*(2400) *<sup>D</sup>*<sup>0</sup>

Data Total fit <sup>0</sup> *K*\*(892) <sup>0</sup> *K*\*(1410) <sup>−</sup> \*(2460) *<sup>D</sup>*<sup>2</sup> *x*<sup>+</sup> = 0*.*04 *±* 0*.*16 *±* 0*.*11 *, y*<sup>+</sup> = 0*.*47 *±* 0*.*28 *±* 0*.*22 *,* weighted according to *S/*(*S* + *B*) and combined. The components are described in the legend. Phys. Rev. D93 (2016) 112018 21

and  $\overline{\textbf{B}}$ 0 and (b)  $\overline{\textbf{B}}$ 0 candidates. Only candidates. Only candidates in the three purests  $\overline{\textbf{B}}$ 

 $2$  (1430) $0$  resonances as well as  $\mathcal{O}(1)$ 

−<br>− π

<sup>+</sup> →*DK* <sup>0</sup> *B*

#### **GLW-Dalitz analysis** 50 100 150 *Br* 0.2 0.4 0.6 0.8 Figure 4: Results of likelihood scans for (a) , (b) *r<sup>B</sup>* and (c) *B*. Figure 3: Projections of the *<sup>D</sup>* ! *<sup>K</sup>*+*K* and ⇡+⇡ samples and the fit result onto *<sup>m</sup>*(*K±*⇡⌥) for (a) *B*<sup>0</sup> and (b) *B*<sup>0</sup> candidates. The data and the fit results in each NN output bin have been **1 Bkgd. Bkgd. Shown in Fig. 10 of Ref. [1] were calculated Fig. 1** is given below.

95.5%

<sup>−</sup> *D*\*

- Cartesian parameters reported  $\alpha^*$  if **Figure** weighted according to *S/*(*S* + *B*) and combined. The components are described in the legend. Figure 3: Projections of the *<sup>D</sup>* ! *<sup>K</sup>*+*K* and ⇡+⇡ samples and the fit result onto *<sup>m</sup>*(*K±*⇡⌥) ±*y*
	-
	- Statistics the biggest factor , *K±*⇡⌥⇡<sup>+</sup>⇡ [56–58] and *D* ! *K*<sup>0</sup> 0.5

 $y_- = -0.35 \pm 0.26 \pm 0.41$  <sup>-1</sup>  $y_- = -0.35 \pm 0.26 \pm 0.41$  $\equiv$ 

- Report quasi-two-body values  $\begin{array}{cccc} \n\cdot & \text{R}^1 & \text{R}^1 & \text{R}^1 & \text{R}^1 & \text{R}^1 \cdot & \text{R}^1 & \text{R}^1 \cdot & \text{R}^1 \cdot & \text{R}^1 & \text{R}^1 \cdot &$  $\alpha_{\pm}$  i.e. the angle between the  $\alpha_{\pm}$  rest frame. The *X*<sup>+</sup>  $\sigma$  are given in Ref. The GammaCombo package [50] is used to evaluate constraints from these results on where the uncertainties are statistical and systematic. The corresponding correlation ± *x*  $\frac{1}{2}$  tusched is  $\frac{1}{2}$ 
	- Help combine with  $B^0 \to D K^{*0}$  results
	- · Coherence factor, relative magnitudes and strong phases Figure 9: Contours at 68 % CL for the (blue) (*x*+*, y*+) and (red) (*x, y*) parameters associated Coherence factor, relative magnitudes and strong phases marked by a circle and a cross, respectively. *The left plot shows the version in Ref. [1], the*

 $\kappa = 0.958_{-0.010}^{+0.005}{}_{-0.010}^{+0.002}$  $\overline{R}_B = 1.02 \frac{+0.03}{-0.01} \pm 0.06$ ,  $\Delta \overline{\delta}_B = 0.02 \frac{+0.03}{-0.02} \pm 0.11$  $\kappa = 0.958^{+0.005}_{-0.005}$   $\bar{B}_B = 1.02^{+0.03}_{-0.03} + 0.06$   $\Delta \bar{\delta}_B = 0.02^{+0.03}_{-0.03} + 0.11$  $-0.010 - 0.040$  *b*  $-0.01$   $-0.01$ 



95.5%

### 10/11/2016 5

95.5%

*D*π S-wave *D*π P-wave <sup>+</sup> \* (2700) *D*s1

### • Several new or updated inputs into the combination • Two body GLW/ADS • Four Update of LHCb  $\cdot$  GGSZ of  $B\to DK$  like decays • GLW-Dalitz  $B^\pm \to D\mathbf{K}^\pm$  ,  $D \to h^+h^{'-}$  $B^{\pm} \rightarrow DK^{\pm}$ ,  $D \rightarrow h^+\pi^-\pi^+\pi^ B^0 \rightarrow D K^{*0}$  ,  $D \rightarrow K^0_S \pi^+ \pi^ B^0 \rightarrow DK^+\pi^-$ ,  $D \rightarrow h^+h^ B^+ \to D K^+, D \to h^+$ <br>Update of LHCb  $\bigwedge^p$  combination  $B \to DK$

# DK Combination

a Doot knowledge from combining of  $\blacksquare$ • Best knowledge from combining all LHCb analyses

with the LHCb detector using a large variety of decay channels. The best sensitivity is decay channels. The best sensitivity is  $\alpha$ 

- interference of *b* ! *u* and *b* ! *c* amplitudes, as described in more detail in Ref. [1]. The • Previous result from 2014 by  $\overline{1}$  by  $\overline{1}$
- channels and updating selected channels to the available dataset of 3 fb1 recorded in  $\frac{1}{1}$  recorded in 2011 • Only  $B \to DK$  like decays  $\boxed{\phantom{a}^{0.8}}$ 
	- $B^+ \rightarrow DK^+, D \rightarrow h^+h^-$ , GLW/ADS, 3 fb<sup>-1</sup>
	- $B^+ \rightarrow DK^+, D \rightarrow h^+\pi^-\pi^+\pi^-,$  quasi-GLW/ADS, 3 fb<sup>-1</sup>
	- $B^+ \rightarrow DK^+, D \rightarrow h^+h^-\pi^0$ , quasi-GLW/ADS,  $3 \text{ fb}^{-1}$
	- $B^+ \to D K^+$ ,  $D \to K_s^0 h^+ h^-$ , model-independent GGSZ,  $3 \text{ fb}^{-1}$
	- $B^+ \to D K^+$ ,  $D \to K_s^0 K^+ \pi^-$ , GLS,  $3 \text{ fb}^{-1}$
	- $B^0 \to DK^+\pi^-$ ,  $D \to h^+h^-$ , GLW-Dalitz, 3 fb<sup>-1</sup>
	- $B^0 \to D K^{*0}$ ,  $D \to K^+ \pi^-$ , ADS, 3 fb<sup>-1</sup>
	- $B^0 \to DK^{*0}, D \to K^0_s \pi^+ \pi^-$ , model-dependent GGSZ, 3 fb<sup>-1</sup>  $\blacksquare$
	- $B^+ \to D K^+ \pi^+ \pi^-$ ,  $D \to h^+ h^-$ , GLW/ADS, 3 fb<sup>-1</sup>
	- $B_s^0 \to D_s^{\mp} K^{\pm}$ , time-dependent,  $1 \text{ fb}^{-1}$ ,



New or updated since the above result

Work in progress:  $3fb^{-1}$ 

10/11/2016

10/11/2016 **Mew - arXiv 1611.03076, old - LHCb-CONF-2014-004** 24 of authors first proposing the methods in Refs. [13–22].

### DK Combination  $\sim$

- -
	-
- Coverage is good

$$
\gamma = (72.2 \, \substack{+6.8 \\ -7.3})^\circ
$$





*rDK*

#### DK Combination  $|{\boldsymbol \kappa}|$ <sup>0</sup> <sup>50</sup> <sup>100</sup> <sup>150</sup> <sup>0</sup>  $\cap$ combination. Dark and light regions show the intervals contained by the intervals containing  $\sim$ <sup>0</sup> <sup>50</sup> <sup>100</sup> <sup>150</sup> <sup>0</sup>

sub-combinations: (blue) *<sup>B</sup>*<sup>+</sup> ! *DK*<sup>+</sup>



0.8

 $\mathcal{L} = \mathcal{L} \times \mathcal{L} \times \mathcal{L}$  ,  $\mathcal{L} = \mathcal{L} \times \mathcal{L} \times \mathcal{L}$ 

, *<sup>D</sup>*<sup>0</sup> ! *<sup>h</sup>*⇡⇡⇡/*hh*<sup>0</sup>

⇡0, (pink) *<sup>B</sup>*<sup>+</sup> ! *DK*<sup>+</sup>

# **S1 Observables measured by LHC**b that have sensitive to the COM bination

• Improvement on 2014 result **Company of a constraint of a best fit value of a**  $B_s$  deca

• Around 2 or 3 degrees more precise  $\frac{1}{2}$ 

> $\gamma \in [64.9, 79.0]$ <sup>°</sup> at 68.3% CL  $\gamma \in [55.9, 85.2]^\circ$  at 95.5% CL

$$
\gamma = (72.2 \, \substack{+6.8 \\ -7.3})^\circ \qquad {}^{\dot{-}} \, {}^{0.8} \Big[
$$

• Still more from Run I? = (72*.*<sup>2</sup> +6*.*<sup>8</sup> 7*.*3) *,*

$$
B_s^0 \to D_s^{\pm} K^{\pm}
$$
  

$$
B^{\pm} \to D^* K^{\pm}
$$
  

$$
B^{\pm} \to D K^{*\pm}
$$





initial *B* meson flavour: (orange) *B*<sup>0</sup>

#### 10/11/2016

*<sup>s</sup>* , (yellow) *B*0, (blue) *B*<sup>+</sup> and (green) the full combination.

# • Several new or updated inputs into the combination • Four Update of LHUD  $B^{\pm} \rightarrow D\sqrt{\phantom{a}}^{\pm}$ ,  $D \rightarrow h^{\pm}h^{\pm}$ of  $B\overset{\text{d}}{\rightarrow} Dh^k$  like decays  $B^\pm \to D \overline{\gamma}^D \to h^+$ Update of LHCb  $\gamma^D$  combination

# Dh Combination

- Try to squeeze sensitivity from $B\to D\pi$  like decays
	- Previous result from 2014
	- Several additional inputs w.r.t. the DK only combination

$$
B^+ \to D\pi, \ D \to h^+h^-
$$

$$
B^+ \to D\pi, \ D \to h^+\pi^-\pi^+\pi^-
$$

- $B^+ \to D\pi$ ,  $D \to h^+h^-\pi^0$
- $B^+ \to D\pi\pi\pi$ ,  $D \to h^+h^-$ 
	- Observables:  $71 \rightarrow 89$  and parameters  $32 \rightarrow 38$



New - arXiv 1611.03076, old - LHCb-CONF-2014-004

#### Dh Combination 95.5% 0 95.5%

68.3%



10/11/2016 30 1-CL arXiv 1611.03076

0.8

68.3%

# Dh Combination

1-CL

LHCb



 $\overline{\mathbf{0}}$ 0  $\overline{a}$ ם<br>- - ^  $50 - 0.9$   $-0.00$ 95.5% Bayesian combination favours low  $r_B^{D\pi}$  solution instead, but everything is consistent at the 2 sigma level

LHCb

 $\frac{1}{\sqrt{2}}$ 

*Br*

LHCb

# Dh Combination

1-CL

LHCb



0.4 Such differences are not uncommon in the presence of a highly non-Gaussian likelihood function

Note that both frameworks find the same  $\mathcal X$  minima

0

LHCb

 $\frac{1}{\sqrt{2}}$ 

 $\sim$  50  $\mu$  60  $\mu$  80  $\mu$  80  $\mu$  80  $\mu$  80  $\mu$  80  $\mu$  80  $\mu$ 

0 0.01 0.02 0.03 0.04 0.05

*Br*

LHCb

# Summary

0

- New inputs to the combinations
	- New decay modes and methods used for the first time
	- Both DK only and Dh combinations performed  $\mathsf{IOf}$
	- Reached the expected Run I sensitivity 0 0.1 0.2 0.3 0.4

$$
\gamma = (72.2 \, \substack{+6.8 \\ -7.3})^\circ
$$

- Time for a rest?
	- Plenty still to do!
	- New decay modes and updates from Run I
	- Should more than double the data sample with Run II Figure 1: 1 CL curves for the *DK* combination obtained with the Plugin method. The 1



0

#### 10/11/2016

### **Outlook**

- What comes next?
	- More channels for both  $B$  and  $D$  decays from Run I and II

$$
B^{+} \to D^{*0}K^{+}
$$
  
\n
$$
B^{0} \to D^{\mp}\pi^{\pm}
$$
  
\n
$$
B_{s}^{0} \to D_{s}^{\mp}K^{\pm}
$$
  
\n
$$
B_{s}^{0} \to D_{s}^{*\mp}K^{\pm}
$$
  
\n
$$
D \to KK\pi\pi
$$
  
\n
$$
D \to K_{S}^{0}\pi\pi\pi^{0}
$$

All are being investigated, some in preparation for CKM 2016

### **Outlook**

• Looking deeper into the crystal ball



- Beauty cross section up by more than a factor 2 and small increases in trigger and selection efficiencies
- Hadronic trigger efficiency should roughly double

### **Outlook**

- Target sub-degree precision
	- Indirect measurements give  $\gamma$  to  $(\frac{+1.0}{-3.7})^{\circ}$
	- Lattice improvements will decrease the uncertainties
	- Expect statistical uncertainties to scale with data samples
	- Systematic uncertainties should also decrease



• Anticipate similar precision to Belle II in upgrade era

### **Conclusion**

- LHCb has made a big impact measuring  $\gamma$ 
	- Hope to halve our uncertainties in Run II
	- Things should get exciting in the upgrade era (2021 ->)
	- We look forward to healthy competition with Belle II
	- Many areas where we can complement each other



10/11/2016





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# CKM picture



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### Gammacombo

- Framework available for anyone to use
	- See HEP Forge for more details
	- http://gammacombo.hepforge.org/web/HTML/index.html
- Used for the combinations in this talk
	- **Frequentist treatment**

# Reading x and y



#### 400 2 body GLW modes **EXALIMACS**  $H \text{W}$  modes  $\mathbf{L}$  , we can be constructed and  $\mathbf{L}$

 $\overline{\phantom{a}}$ • Not much to see...





 $A_\pi^{KK} = -0.0145 \pm 0.0050 \pm 0.0017\, A_\pi^{\pi\pi} = 0.0043 \pm 0.0086 \pm 0.0031$ 

### GLW-Dalitz

Table 8: Results for the complex coefficients  $c_j$  from the fit to data. Uncertainties are statistical only. All reported quantities are free to vary in the fit, except that the  $D_2^*(2460)^-$  component is fixed as a reference amplitude, and the magnitude of the  $D_{s1}^*(2700)^+$  component is constrained. The  $K^+\pi^-$  S-wave is the coherent sum of the  $K_0^*(1430)^0$  and the nonresonant  $K\pi$  S-wave component [45].



### GLW-Dalitz



#### 10/11/2016 44 Phys. Rev. D93 (2016) 112018(left) *D*<sup>0</sup>*K*<sup>+</sup>⇡ and (right) *D*+*K*<sup>+</sup>⇡. In these illustrative examples the following values are used: % = 1*.*5, = 20

#### *a 10/11/2016*

#### DK combination (frequentist) 0.8 1 L 0.8

1-CL

0.4



0.4

45 Table 4:  $C$  and central values for the parameters  $\alpha$  intervals and central values for interest in the frequentist in the frequency of intervals  $\alpha$ 10/11/2016 arXiv 1611.03076

1-CL

0.4

### DK combination (Bayesian)



# DK combination 2D (frequentist)



# DK combination 2D (Bayesian)



### DK results summary

Table 3: Confidence intervals and central values for the parameters of interest in the frequentist  $DK$  combination.



Table 6: Credibile intervals and most probable values for the hadronic parameters extracted from the  $DK$  Bayesian combination.



Bayesian

# Dh combination (frequentist)



# Dh combination (Bayesian)



### Dh combination (frequentist)



# Dh combination (Bayesian)



# Dh combination 2D (frequentist)



# Dh combination 2D (Bayesian)



### Dh results summary

Table 4: Confidence intervals and central values for the parameters of interest in the frequentist  $Dh$  combination.

| Observable                   | Central value | 68.3% Interval   | 95.5% Interval   | 99.7% Interval   |
|------------------------------|---------------|------------------|------------------|------------------|
| $\gamma(^\circ)$             | 73.5          | [70.5, 76.8]     | [56.7, 83.4]     | [40.1, 90.8]     |
| $r_R^{DK}$                   | 0.1017        | [0.0970, 0.1064] | [0.0914, 0.1110] | [0.0844, 0.1163] |
| $\delta_R^{DK}$ (°)          | 141.6         | [136.6, 146.3]   | [127.2, 151.1]   | [114.6, 155.7]   |
| $r_B^{DK*0}$                 | 0.220         | [0.173, 0.264]   | [0.121, 0.307]   | [0.000, 0.355]   |
| $\delta_B^{DK^{*0}}(^\circ)$ | 188           | [168, 211]       | [148, 239]       | [120, 280]       |
| $r_B^{D\pi}$                 | 0.027         | [0.0207, 0.0318] | [0.0020, 0.0365] | [0.0008, 0.0425] |
| $\delta_B^{D\pi}$ (°)        | 348.3         | [343.2, 352.9]   | [220.5, 356.4]   | [192.9, 359.8]   |

Table 7: Credibile intervals and most probable values for the hadronic parameters extracted from the  $Dh$  Bayesian combination.



# Bayesian

### Systematic limitations

#### Limiting factors in the high-statistics era

Where will we become limited, as things stand:

- Most<sup>1</sup>  $B \to DK$  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 ( $\rightarrow$  systematic  $\sim 1^{\circ}$ )
	- Measurement in  $D \to K\pi$  (Int. J. Mod. Phys. Conf. Ser. 31 1460305)
	- Preliminary results in  $D \to K^0_S \pi \pi$
- 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



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