Measuring γ in $B^{\pm} \to (K^+K^-\pi^+\pi^-)_D K^{\pm}$ decays

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# Outline

Background

- 4-year MPhys in Oxford
  - Performance of monolithic CMOS sensors
  - Prof Daniela Bortoletto
- CERN Summer Student 2019
  - Beam loss reduction in TT20 transfer line
  - Dr Yann Dutheil, Dr Matthew Fraser
- Oxford Summer Student 2018
  - Study of PDF uncertainties in W-boson mass measurement
  - Prof Chris Hays
- RAL Summer Student 2018
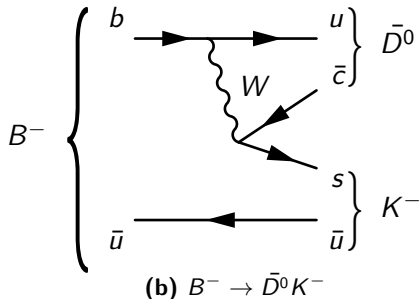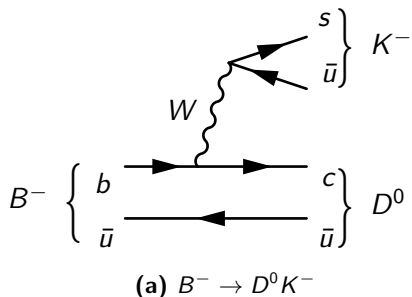 - Bending magnets in accelerator simulations (Dr Chris Rogers)

Unitarity of CKM matrix: $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

Define $\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$
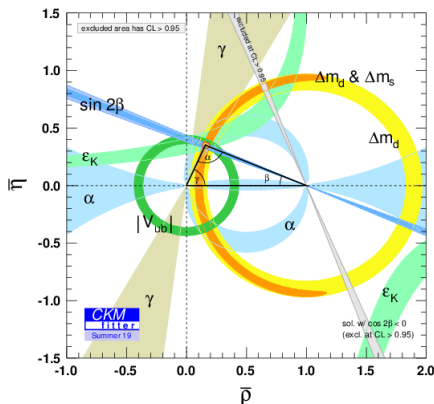
CKMfitter Group (J. Charles et al.), Eur. Phys. J. C41, 1-131 (2005)

(a) $B^- \to D^0 K^-$

(b) $B^- \to \bar{D}^0 K^-$

Similar diagrams for $B^+ \to DK^+$, with $\gamma \to -\gamma \implies$

Inteference when D^0 and $\bar{D}^0$ decay into a common final state

Single most precise measurement: $\gamma = (68.7^{+5.2}_{-5.1})°$ arXiv:2010.08483
$B^\pm \to DK^\pm$, $B^\pm \to D\pi^\pm$, $D \to K^0_S h^+ h^-$
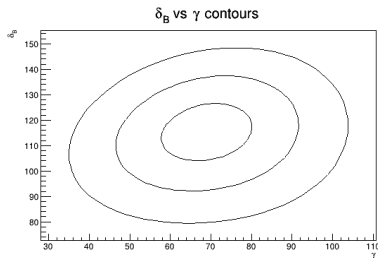
The $D \to K^+K^-\pi^+\pi^-$ decay

- Estimated 2000 events from LHCb Run 1 and 2

- First proposed by G. Wilkinson and J. Rademacker (arXiv:hep-ph/0611272)
    - Estimated γ precision: $14°$ with 1000 events
    - Amplitude analysis: Isobar model

- CLEO amplitude analysis (arXiv:1201.5716)
    - Estimated γ precision: $11°$ with 2000 events

- LHCb amplitude analysis (arXiv:1811.08304)
    - AmpGen for generating events and unbinned fit

- Other 4-body decay studies:
    - Binned analysis of $K_S^0\pi^+\pi^-\pi^0$ by Belle arXiv:1908.09499
    - Inclusive analysis of $h^\pm\pi^\mp\pi^+\pi^-$ arXiv:1906.08297, arXiv:1709.05855, arXiv:1603.08993 by LHCb
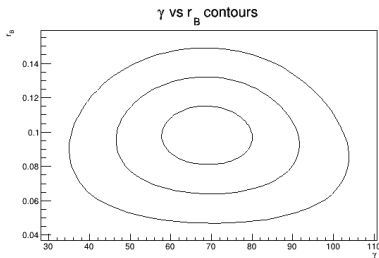
Unbinned fit with amplitude model

- Initial values:
  - $\gamma = 75°$
  - $\delta_B = 130°$
  - $r_B = 0.1$
- Results from unbinned fit of 2×10^3 events:
  - $\gamma = (69 \pm 11)°$
  - $\delta_B = (115 \pm 11)°$
  - $r_B = 0.098 \pm 0.017$
- Results from unbinned fit of 2×10^4 events:
  - $\gamma = (77.1 \pm 3.5)°$
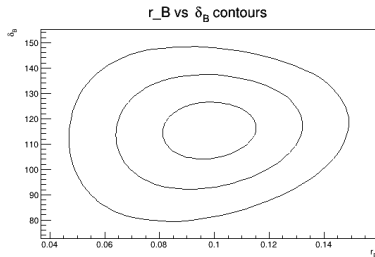 - $\delta_B = (129 \pm 4)°$
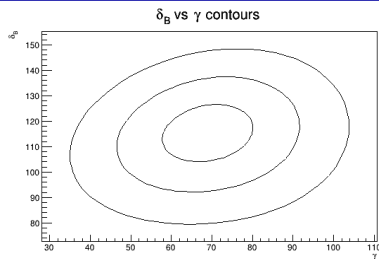 - $r_B = 0.093 \pm 0.006$
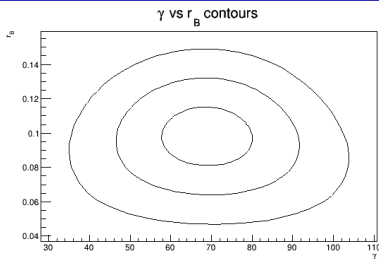
(a) γ vs δ_B

(b) γ vs r_B

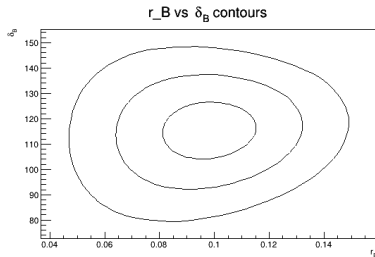(c) r_B vs δ_B

Unbinned fit of 2×10^4 events with amplitude model

(a) γ vs δ_B

(b) γ vs r_B

(c) r_B vs δ_B

Binned fit of $D \to K^+ K^- \pi^+ \pi^-$

$$\mathcal{A}(B^- \to (K^+ K^- \pi^+ \pi^-)_D K^-) \propto \mathcal{A}(D^0 \to K^+ K^- \pi^+ \pi^-)$$
$$+ \mathcal{A}(\bar{D}^0 \to K^+ K^- \pi^+ \pi^-) r_B e^{i(\delta_B - \gamma)}$$
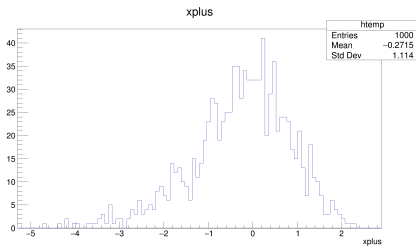
Event yield in bin i

$$N_i^- = h_{B^-} \left(K_i + \left(x_-^2 + y_-^2 \right) \bar{K}_i + 2\sqrt{K_i \bar{K}_i} \left(x_- c_i + y_- s_i \right) \right)$$
$$N_i^+ = h_{B^+} \left(\bar{K}_i + \left(x_+^2 + y_+^2 \right) K_i + 2\sqrt{K_i \bar{K}_i} \left(x_+ c_i - y_+ s_i \right) \right)$$

CP-violating observables

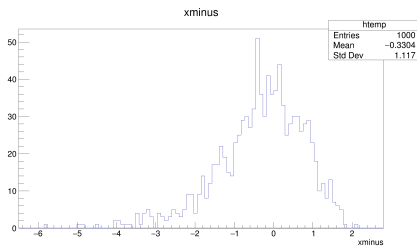$$x_\pm = r_B \cos(\delta_B \pm \gamma), \quad y_\pm = r_B \sin(\delta_B \pm \gamma)$$

- c_i, s_i: Amplitude-averaged strong phase difference of D decay
- Measure c_i and s_i at BES III detetector
- Can measure K_i and $\bar{K}_i$ at both LHCb and BES III
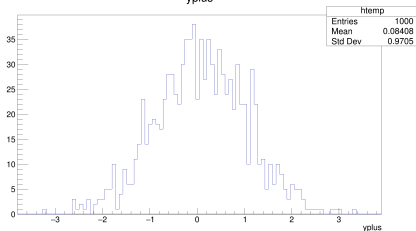- Need to divide phase space into bins
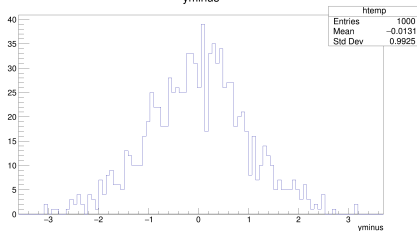
Pull study with 2×10^3 events
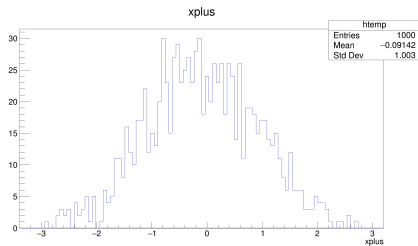

(a) x_+ pull

(b) x_- pull

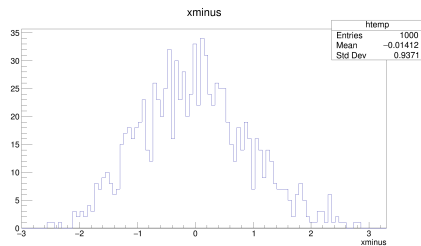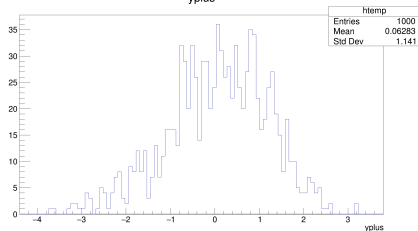**(c)** y_+ pull
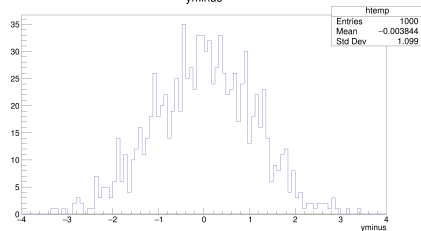
(d) y_- pull

Pull study with 2×10^4 events

(a) x_+ pull

(b) x_- pull

(c) y_+ pull

(d) y_- pull

Parameterisation of phase space

- 4-body phase space is 5-dimensional
- Convenient to choose rectangular coordinates

Phase space parameterisation

$$x_1 = m(K^+\pi^+) + \alpha$$
$$x_2 = m(K^-\pi^-) + \alpha, \quad \alpha = \min(m(K^+\pi^+), m(K^-\pi^-))$$
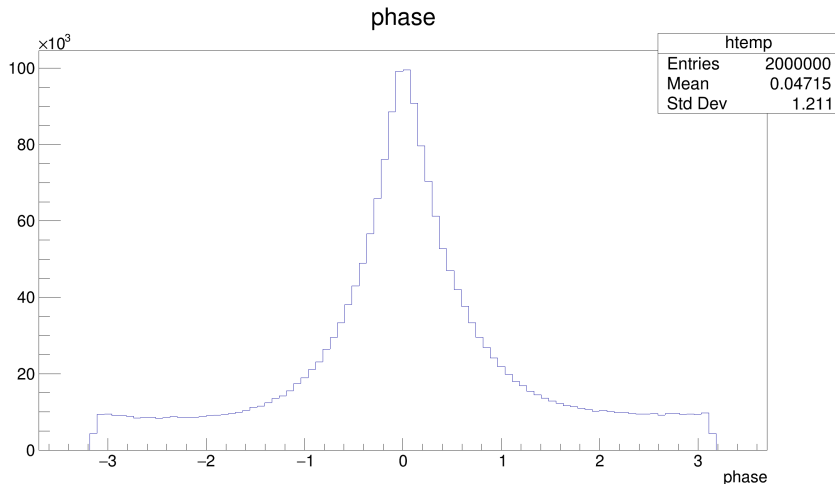$$x_3 = \cos(\theta_+), \quad \text{(Helicity angles)}$$
$$x_4 = \cos(\theta_-)$$
$$x_5 = \phi$$

- Define binning scheme in terms of these coordinates
- Ideally have a constant strong phase difference in each bin

Histogram of strong phase difference

Strong phase difference from amplitude model:

Histogram of strong phase difference

Place cuts $x_3 > 0.8, x_4 > 0.8$:

phase {X3 > 0.8 && X4 > 0.8}

htemp	
Entries	166523
Mean	0.01058
Std Dev	0.3787