Binning scheme for γ measurement in $B^{\pm} \to (K^+K^-\pi^+\pi^-)_D K^{\pm}$ decays

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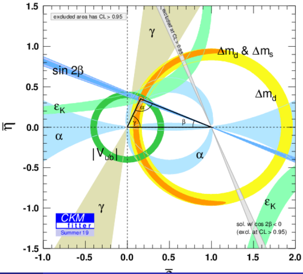
16th December 2020



Outline

1. Background
2. Unbinned fit with amplitude model
3. Binned fit of $D \to K^+K^-\pi^+\pi^-$

Current progress

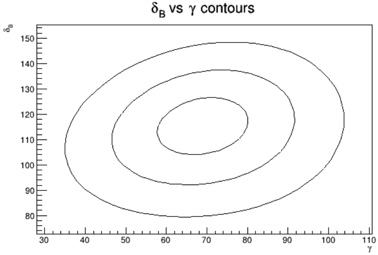
- Events generated in AmpGen using amplitude model arXiv:1811.08304
  - Assumed event yield: 2000 (1000 B^+, 1000 B^-)
  - Assumed parameters in toy model: $\gamma = 75^\circ$, $\delta_B = 130^\circ$, $r_B = 0.1$
- Unbinned fit using SimFit in AmpGen
- Binned fit and pull studies
- Develop suitable binning scheme

Unbinned fit with amplitude model

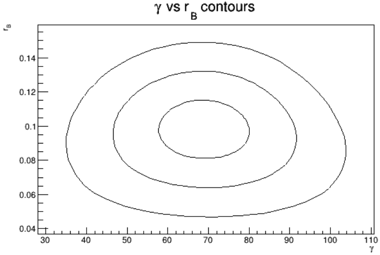
$$
\begin{aligned}
\mathcal{A}(B^- \to (K^+K^-\pi^+\pi^-)_D K^-) =& \mathcal{A}_B \mathcal{A}(D^0 \to K^+K^-\pi^+\pi^-) \\
&+ \mathcal{A}_B \mathcal{A}(\bar{D}^0 \to K^+K^-\pi^+\pi^-) r_B e^{i(\delta_B - \gamma)}
\end{aligned}
$$

- $\mathcal{A}(D \to K^+K^-\pi^+\pi^-)$ obtained from amplitude model
- Fit with γ, δ_B and r_B as free parameters
- Results from unbinned fit of 2×10^3 events:
  - $\gamma = (69 \pm 11)^\circ$
  - $\delta_B = (115 \pm 11)^\circ$
  - $r_B = 0.098 \pm 0.017$

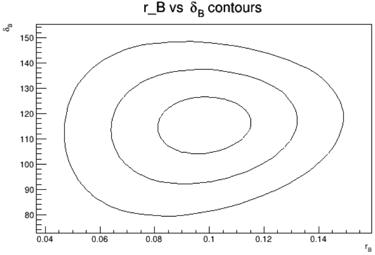
Unbinned fit of 2×10^3 events with amplitude model



(a) γ vs δ_B



(b) γ vs r_B



(c) r_B vs δ_B

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

$$\mathcal{A}(B^- \to (K^+K^-\pi^+\pi^-)_D K^-) = \mathcal{A}_B \mathcal{A}(D^0 \to K^+K^-\pi^+\pi^-) + \mathcal{A}_B \mathcal{A}(\bar{D}^0 \to K^+K^-\pi^+\pi^-) r_B e^{i(\delta_B - \gamma)}$$

Event yield in bin i

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

CP-violating observables

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

Pull studies

- Used an arbitrary and naive binning scheme with 4 bins
- $x_\pm$ pulls show asymmetric tails for 2×10^3 events
- Pulls for γ, δ_B, r_B are rubbish

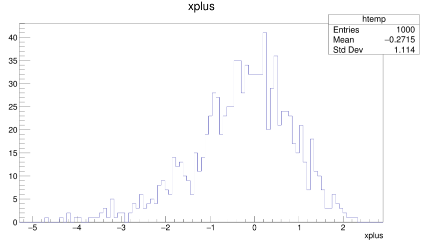
Naive binning scheme

Split phase space along the boundaries $E_{K^+} = E_{K_-}$ and $E_{\pi^+} = E_{\pi^-}$
Bin 1: $E_{K^+} > E_{K^-}, \quad E_{\pi^+} > E_{\pi^-}, \ldots$

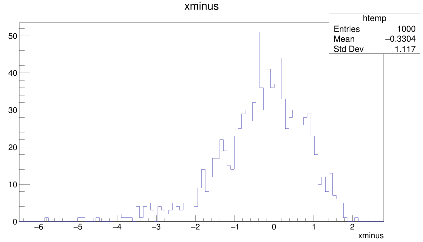
D decay hadronic parameters

$$c_i = \frac{\int_i \mathrm{d}\Phi \, |\mathcal{A}(D^0)||\mathcal{A}(\bar{D}^0)| \cos(\delta_D)}{\sqrt{\int_i \mathrm{d}\Phi \, |\mathcal{A}(D^0)|^2 \int_i \mathrm{d}\Phi \left|\mathcal{A}(\bar{D}^0)\right|^2}}, \quad K_i = \frac{\int_i \mathrm{d}\Phi \, |\mathcal{A}(D^0)|^2}{\sum_j \int_j \mathrm{d}\Phi \, |\mathcal{A}(D^0)|^2}$$

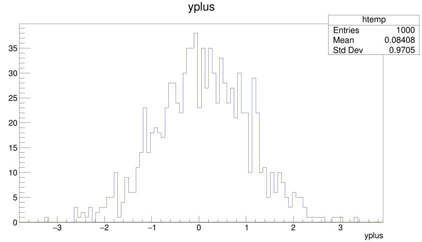
Pull study with 2×10^3 events



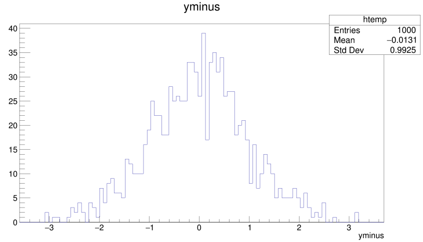
(a) x_+ pull



(b) x_- pull



(c) y_+ pull



(d) y_- pull

Need a more sophisticated binning scheme!

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

Phase space parameterisation

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

- Define binning scheme in terms of these coordinates
- Ideally have a constant strong phase difference in each bin
- Determine binning scheme based on amplitude model, but final fit is model independent

Summary and next steps

Summary:

- Unbinned fit: 11° precision with 2000 events
- Binned fit: 15.3° with 8 bins
- Can reach 14.8° with > 30 bins

Any suggestions for improving the binning scheme?