Determination of CKM angle ϕ_3 using $B^- \to D^{*0}(D^0(K_s^0 h^+ h^-)\pi^0/\gamma)h^-$.

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SM accounts for CP violation through Kobayashi-Maskawa mechanism.

- The weak interactions of quarks are described in terms of the unitary Cabibbo-Kobayashi-Maskawa (CKM) matrix.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \equiv \hat{V}_{\mathrm{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \qquad (1)$$

Wolfenstein parametrisation:

$$V_{\mathrm{Wolf}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2, & \lambda, & A\lambda^3(\rho - i\eta \\ & & +i\eta\frac{1}{2}\lambda^2) \\ -\lambda, & 1-\frac{1}{2}\lambda^2 & A\lambda^2\left(1+i\lambda^2\eta\right) \\ A\lambda^3(1-\rho-i\eta), & -A\lambda^2, & 1 \end{pmatrix} \qquad (2)$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \qquad (3)$$

The unitarity triangle

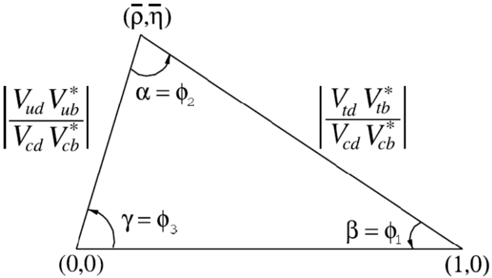


Figure: Unitarity Triangle

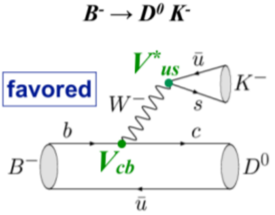
- We are interested in angle ϕ_3 (also denoted as γ) defined as,

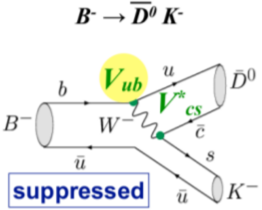
$$\phi_3 = \gamma \equiv \arg\left[-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*\right] \tag{4}$$

- ϕ_3 is least well known parameter in CKM triangle.
- Precise measurement will lead to a better understanding of SM description of CP violation.

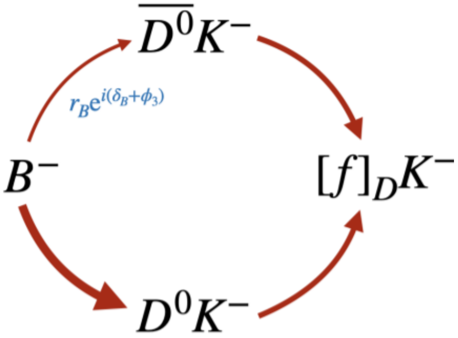
Extraction of CKM angle ϕ_3

- $B \to D^{(*)0}h,\ h = \pi, K$ are senstive to ϕ_3
- The tree-level nature of amplitudes involved allows theoretically clean extraction of ϕ_3.
- The $B \to D^* h$ decay, where $D^* \to D\pi^0$ or $D\gamma$ excibits CP-violating effects when B decays accessible to both D^0 and $\bar{D}^0$ mesons are studied.
- ϕ_3 is the phase between $b \to u\bar{c}s$ and $b \to c\bar{u}s$ transition.
- $b \to u\bar{c}s$: favored transition
- $b \to c\bar{u}s$: CKM and colour suppressed





Extraction of CKM angle ϕ_3



$$\frac{\mathcal{A}^{\text{suppr.}}\left(B^- \to \overline{D^{(*)0}}K^-\right)}{\mathcal{A}^{\text{favor.}}\left(B^- \to D^{(*)0}K^-\right)} = r_B e^{i(\delta_B+\phi_3)} \quad (5)$$

- Common final states allow interference between the two paths
- Interference gives access to the phase
- We can measure ϕ_3 by exploiting the interference between $B^- \to D^{(*)0}h^-$ and $B^- \to \bar{D}^{(*)0}h^-$ where the D^0 and $\bar{D}^0$ decay to self-conjugate multi-body final states $K_s hh$: GGSZ method.

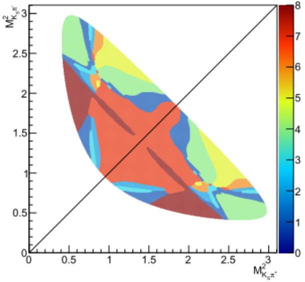
We use the final states $D^0/\bar{D}^0$ decaying to $K_S h^+ h^-$, $h = \pi, K$

BPGGSZ method

- Uses self-conjugate multi-body $D(K_S^0 h^- h+)$ final states
- Sensitivity to ϕ_3 by comparing D Dalitz distributions of B^+ and B^-
- Fit D Dalitz plot with full amplitude model.

$$A_{B^+} = A_{\bar{D}}\left(m_-^2, m_+^2\right) + r_B e^{i(\delta_B - \phi_3)} A_D\left(m_-^2, m_+^2\right) \tag{6}$$

- $A_{\bar{D}}\left(m_-^2, m_+^2\right)\left[A_D\left(m_-^2, m_+^2\right)\right]$ is the $\bar{D}^0 \to K_{\mathrm{S}}^0 h^+ h^-$ $\left[D^0 \to K_{\mathrm{S}}^0 h^+ h^-\right]$ decay amplitude
- $m_\pm^2$ = squared invariant masses of $K_{\mathrm{S}}^0 h^+$: D Dalitz plot variables



- In presence of **CP Violation** expect differences between $B^{(+)}$ and $B^{(-)}$ distributions
- The magnitude and position of the differences are driven by the values of r_B,δ_B,ϕ_3 and the physics of the D decay

- But model-independent analysis have model uncertainty upto $3^o - 9^o$

BPGGSZ : Binned model-independent approach

- Optimal (non-uniform) binning of the D Dalitz plot which gives the maximum sensitivity to ϕ_3
- Observed yields in each bin can be related to physics parameters of interest and D^0 decay information

$$\mathbf{N}_i^{\pm} = \mathbf{h}_\mathrm{B} \pm \left[\mathrm{F}_i + \mathbf{r}_\mathrm{B}^2 \overline{\mathbf{F}}_i + 2\sqrt{\mathrm{F}_i \overline{\mathrm{F}}_i} \left(\mathrm{c}_i \boldsymbol{x}_\pm + \mathrm{s}_i \boldsymbol{y}_\pm\right)\right] \tag{7}$$

- $h_{B\pm}$: Normalization constant
- Physics parameters of interest : $(x_\pm, y_\pm) = r_B \left(\cos\left(\phi_3 + \delta_B\right), \sin\left(\phi_3 + \delta_B\right)\right)$
- Amplitude averaged strong phase differences between $\bar{D}^0$ and D^0 over i^{th} bin are obtained from external charm factories like CLEO and BESIII
- Fraction of pure D^0 decay to bin i taking into account the reconstruction and selection efficiency

Selection :

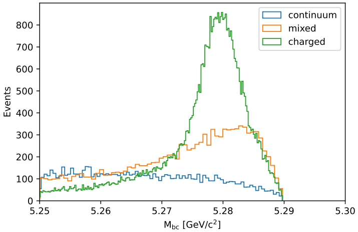
- The small $D^* - D$ mass difference and conservation of angular momentum in $D^* \to D\pi^0$ and $D\gamma$ results in distinctive signatures for $B \to D^* h$ signal in the Dh invariant mass.
- $B \to D^* h$ yields obtained with a partial reconstruction technique.

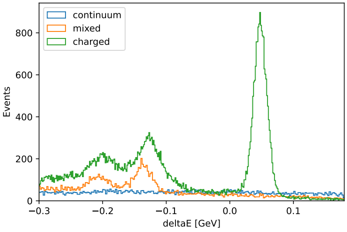
- transverse impact parameter $|\text{dr}| < 0.2$ cm
- longitudinal impact parameter $|\text{dz}| < 1$ cm
- $cos\theta \geq$ -0.6 for prompt tracks
- binary likelihood-ratio kaonID $>$ 0.2 for D daughters
- $1.85 < M_{D^0} < 1.88$ GeV$/c^2$ $\to$ massKFit() has been applied
- $M_{bc} > 5.25 GeV/c^2$
- $-0.13 < \Delta E < 0.18$ GeV
- $0.487 < M_{K_s} < 0.508$ $\to$ massKFit() has been applied
- FBDTKs selection
- MC: 1 ab^{-1} MC14ri

Continuum Suppression

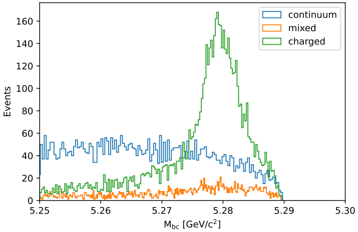
- Training variables: KSFW moments (hoo0,hso02,hso12)
- $\cos\theta_B$: The absolute value of the cosine of the angle between the B candidate and the beam axis in the e^+e^- center-of-mass frame
- $\cos\theta_B^{ROE}$: Cosine of the angle between the thrust axis of the signal B and the thrust axis of ROE
- B_{thrust} : Magnitude of the signal B thrust axis
- ΔZ : Z(Brec) - Z(Btag)
- $\mid qr \mid$: Flavor-tagger output

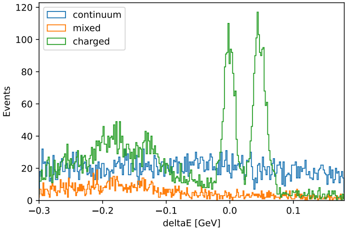
Pion Enhanced(binary KaonID < 0.6)





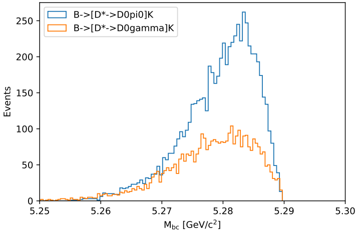
Kaon enhanced (binary KaonID > 0.6)

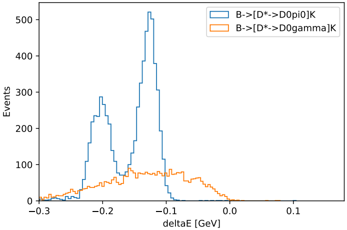




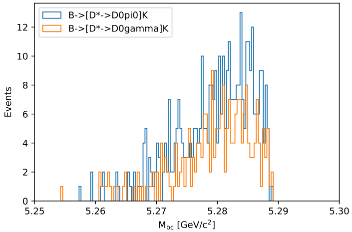
Truth-matched sample:

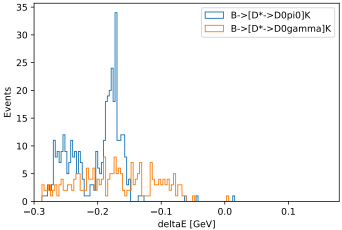
$B \rightarrow D^{*0}(\pi^0/\gamma)\pi$





$B \rightarrow D^{*0}(\pi^0/\gamma)K$





Summary

- Aim of this analysis is the model-independent measurement of the CKM angle ϕ_3 using $B \to D^* h$.
- $B \to DK$ channel is reconstructed in 1 ab^{-1} of generic MC.
- Since the π^0 or γ from the D^* decay is not reconstructed, fully reconstructed $B^- \to Dh^-$ and partially reconstructed $B^- \to D^* h^-$ candidates contain the same reconstructed particles and thus appear in the same sample.
- The next immediate step would be to identify the background beneath the signal using truth-matching information and topology analysis.