

$D \rightarrow K^+ K^- \pi^+ \pi^-$ analysis at LHCb and BESIII

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1 LHCb

- Summary of LHCb analysis status

2 BESIII

- Previously: Measurement of CP even fraction F_+
- $K_S\omega$ CP even tag using sPlot
- F_+ measurement with $K_S\pi\pi$ tag

3 Summary

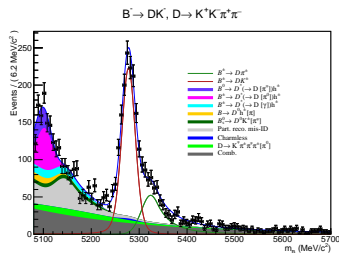
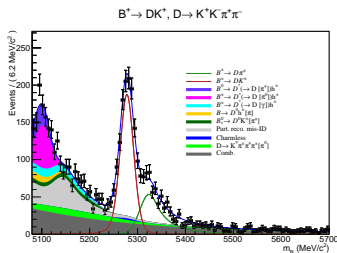
$B^\pm \rightarrow (K^+ K^- \pi^+ \pi^-)_D h^\pm$ GGSZ+GLW analysis at LHCb

$$B^\pm \rightarrow (K^+ K^- \pi^+ \pi^-)_D h^\pm$$

GGSZ+GLW analysis at LHCb

Summary of LHCb analysis status

- Previously on γ measurement in $B^\pm \rightarrow Dh^\pm$, $D \rightarrow K^+K^-\pi^+\pi^-$:
 - ① Model-independent binned GGSZ and inclusive GLW analysis
 - ② Initial ANA note draft circulated in November
 - First round of comments received and replies have been sent back
 - No further comments from 2/3 reviewers
 - Still waiting for the last reply
 - ③ All systematics studies finished
 - ④ Potential problem: s_i sign might be wrong



s_i sign problem

- Amplitude model gives us: $A(\Phi) = \sum_k a_k S_k(\Phi)$
- Flavour-tagged LHCb data measures: $|A(\Phi)|^2$
- Cannot measure absolute sign of a_k phase

Resonance	LHCb model phase (rad)	CLEO model (rad)
$D^0 \rightarrow [\phi(1020)\rho^0]_{L=0}$	0 (fixed)	0 (fixed)
$D^0 \rightarrow K_1(1400)^+ K^-$	1.05	-1.79
$D^0 \rightarrow K_1(1270)^+ K^-$	2.02	-2.56

- BESIII data needed to determine this sign!
- Reconstruct $KK\pi\pi$ vs $K_{S,L}\pi\pi$ double tags:

$$M_{i,j} \propto (K_i K'_{-j} + K_{-i} K'_j - 2\sqrt{K_i K_{-i} K'_j K'_{-j}}(c_i c'_j + s_i s'_j))$$

$D \rightarrow K^+ K^- \pi^+ \pi^-$ strong-phase analysis as BESIII

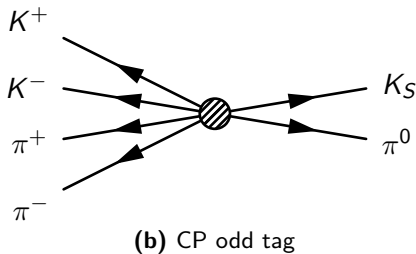
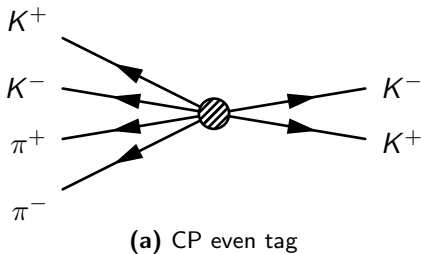
$$D \rightarrow K^+ K^- \pi^+ \pi^-$$

strong-phase analysis as BESIII

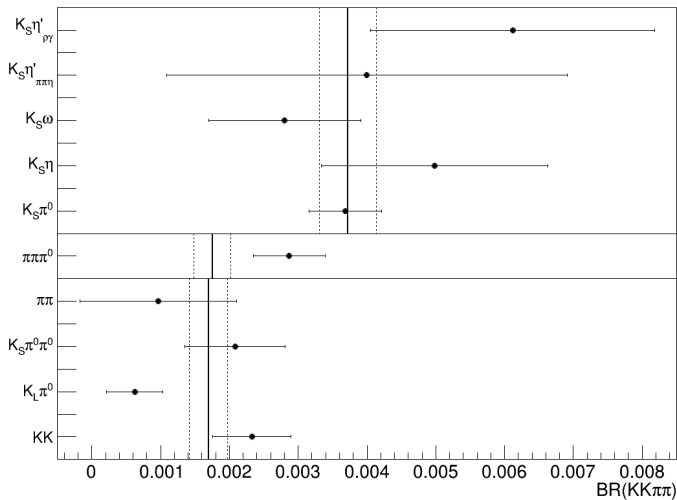
Previously: Measurement of CP even fraction F_+

- BESIII: e^+e^- collider at $\psi(3770) \rightarrow D^0\bar{D}^0$ threshold
- Reconstruct signal mode $D \rightarrow KK\pi\pi$ and a tag mode $D \rightarrow f$
- Signal mode is quantum correlated with tag mode
- Measure BF with CP even/odd tags to determine F_+

$$\text{BF}(KK\pi\pi|f) = \text{BF}(KK\pi\pi) \times (1 - \lambda_{\text{CP}}(2F_+ - 1))$$

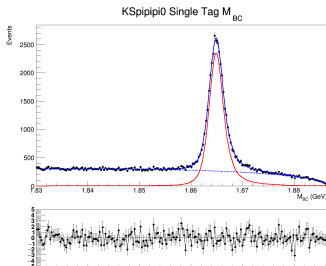


$D^0 \rightarrow KK\pi\pi$ BF asymmetry

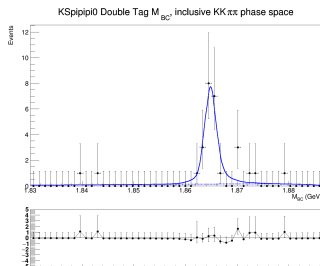


$K_S\omega$ CP even tag using sPlot

- $D \rightarrow K_S\omega$ is CP even
- CP-even contamination from non-resonant $D \rightarrow K_S\pi\pi\pi^0$
 - $F_+(K_S\pi\pi\pi^0) = 0.238 \pm 0.012 \pm 0.012$ from CLEO



(a) Single tag



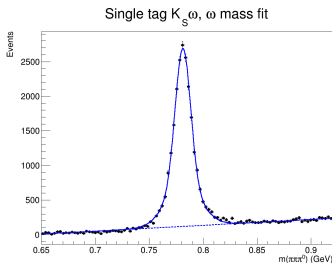
(b) Double tag

Figure 2: $D \rightarrow K_S\pi\pi\pi^0$ D mass (beam constrained)

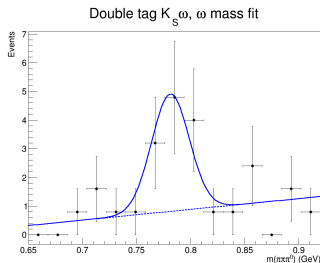
$K_S\omega$ CP even tag using sPlot

- Strategy:

- 1 From D mass fit, remove non- $K_S\pi\pi\pi^0$ background using sPlot
- 2 Fit $\pi\pi\pi^0$ invariant mass to obtain $K_S\omega$ yield



(a) Single tag



(b) Double tag

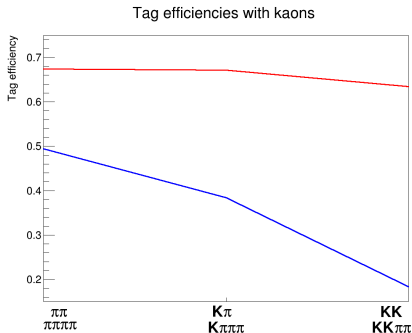
Figure 3: $\pi\pi\pi^0$ invariant mass in $D \rightarrow K_S\pi\pi\pi^0$

F_+ measurement with $K_S\pi\pi$ tag

- With $K_S\pi\pi$, increase sensitivity through binning of $K_S\pi\pi$ phase space

$$M_i \propto (K_i + K_{-i} - 2\sqrt{K_i K_{-i}} c_i (2F_+ - 1))$$

- Problem: $KK\pi\pi$ reconstruction efficiency is too low \rightarrow Low yields!



- Likely explanation: Softer kaons \rightarrow Kaons get stuck inside tracker

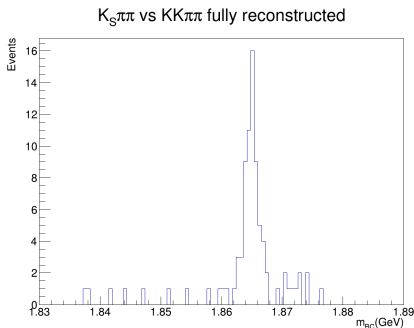
F_+ measurement with $K_S\pi\pi$ tag

- Solution: Partially reconstructed $KK\pi\pi$
- Strategy:
 - 1 Reconstruct $D \rightarrow K_S\pi\pi$
 - 2 Require 3 remaining good tracks consistent with $K\pi\pi$
 - 3 Use missing mass to reconstruct missing kaon

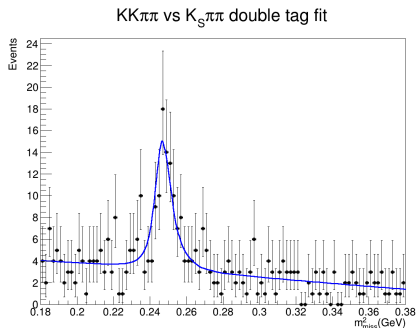
Mode	Inclusive yield	Double tag efficiency
$K_S\pi\pi$ (fully reconstructed)	67.2	6.63 ± 0.04
$K_S\pi\pi$ (partially reconstructed)	85.9	6.50 ± 0.03
$K_L\pi\pi$ (partially reconstructed)	176.9	7.29 ± 0.04

Partially reconstructed $KK\pi\pi$ vs $K_S\pi\pi$

- Main challenge with partially reconstructed $KK\pi\pi$: $K\pi\pi\pi\pi^0$
- Require no π^0 candidates



(a) Fully reconstructed



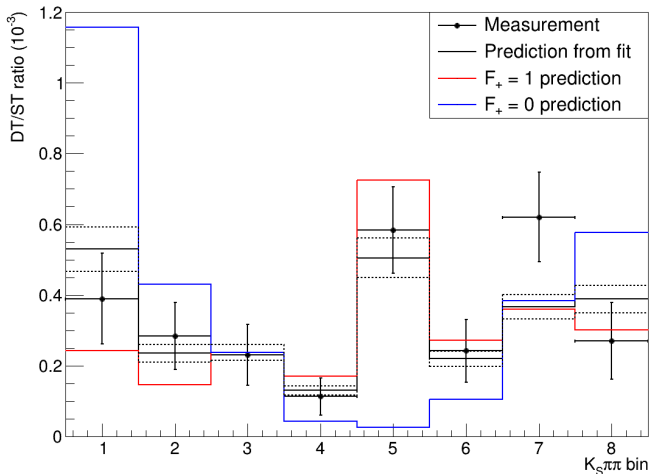
(b) Partially reconstructed

Figure 4: $KK\pi\pi$ vs $K_S\pi\pi$

F_+ measurement with $K_S\pi\pi$ tag

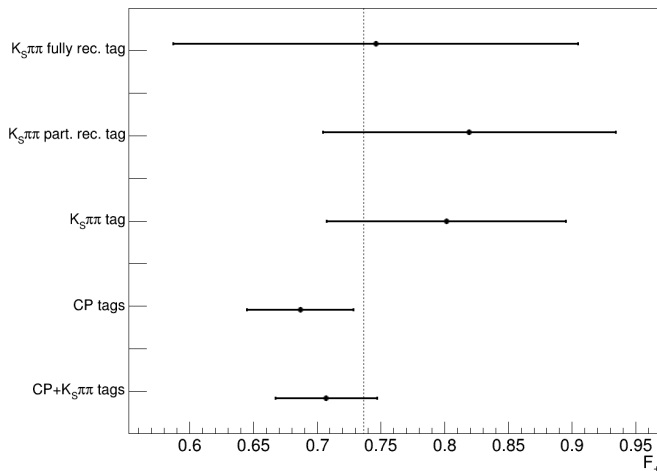
- Combine fully and partially reconstructed $KK\pi\pi$ vs $K_S\pi\pi$ to fit for F_+

$KK\pi\pi$ vs $K_S\pi\pi$ double tag yields



Combination of F_+ measurements

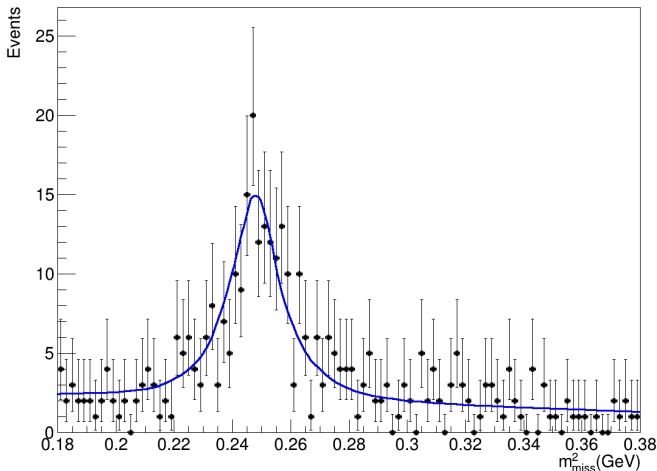
Measurement of CP even fraction F_+ in $D \rightarrow K K \pi \pi$



Next step: Include $K_L\pi\pi$ as well

- Irreducible background from $K_S\pi\pi$ with $K_S \rightarrow \pi^0\pi^0$
- $K_S\pi\pi$ has opposite quantum correlation which must be accounted for

KK $\pi\pi$ vs $K_L\pi\pi$ double tag fit



- LHCb $B^\pm \rightarrow (K^+ K^- \pi^+ \pi^-)_D h^\pm$ GGSZ+GLW analysis:
 - 2/3 reviewers have no further comments, waiting for final reply
 - Sign of s_i must be resolved
- BESIII $D \rightarrow K^+ K^- \pi^+ \pi^-$ strong-phase analysis:
 - $K_S \omega$ tag added to F_+ combination using sPlot
 - Partially reconstructed $KK\pi\pi$ vs $K_S\pi\pi$ shows promising results
 - F_+ measurement performed in $KK\pi\pi$ vs $K_S\pi\pi$ binned analysis
 - Next steps:
 - Perform F_+ measurement with $K_L\pi\pi$
 - Add CP tags $K_L\pi^0\pi^0$, $K_L\omega$ to F_+ combination

Thank you!