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

Martin Tat

Oxford LHCb

21st February 2022

Outline

$$B^{\pm} \to (K^+ K^- \pi^+ \pi^-)_D h^{\pm}$$

GGSZ+GLW analysis at LHCb

Summary of LHCb analysis status

- Previously on γ measurement in $B^{\pm} \to Dh^{\pm}$, $D \to K^+K^-\pi^+\pi^-$:
  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
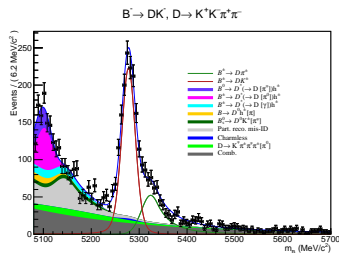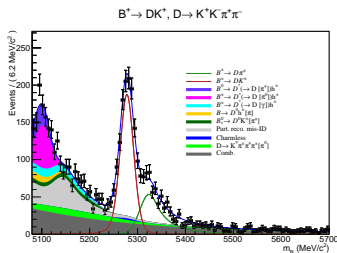
s_i sign problem

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

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

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

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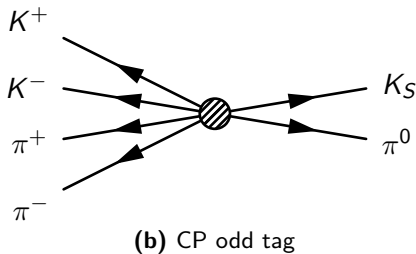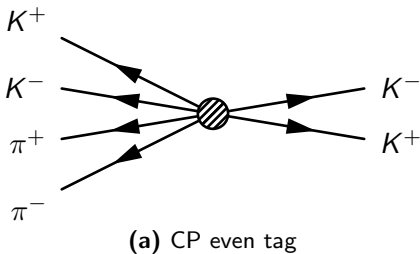
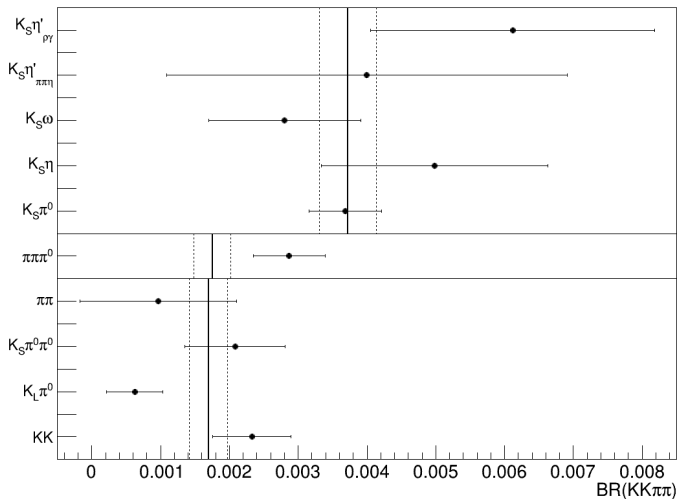$$D \to K^+ K^- \pi^+ \pi^-$$

strong-phase analysis as BESIII

Previously: Measurement of CP even fraction F_+

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

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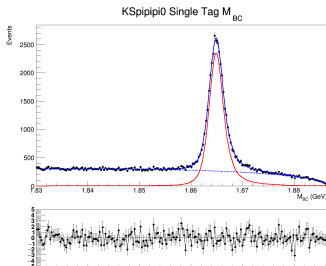

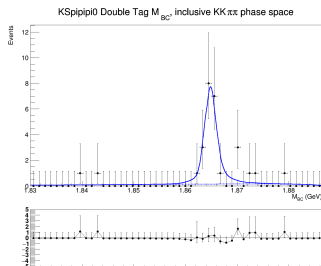**(a)** CP even tag

(b) CP odd tag

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

$K_S\omega$ CP even tag using sPlot

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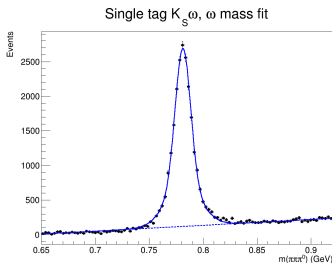 - $F_+(K_S\pi\pi\pi^0) = 0.238 \pm 0.012 \pm 0.012$ from CLEO

(a) Single tag

(b) Double tag

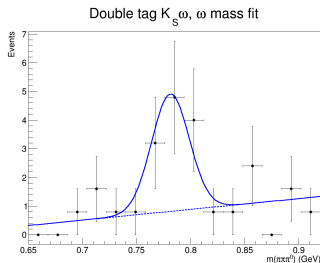**Figure 2:** $D \to K_S\pi\pi\pi^0$ D mass (beam constrained)

$K_S\omega$ 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
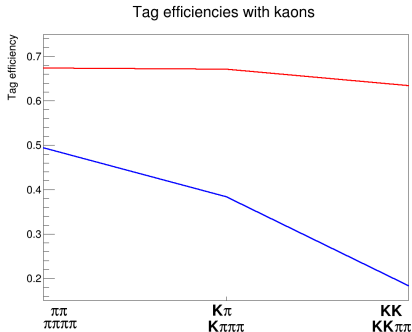

(a) Single tag   **(b)** Double tag

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

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

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

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

- Likely explanation: Softer kaons $\rightarrow$ Kaons get stuck inside tracker
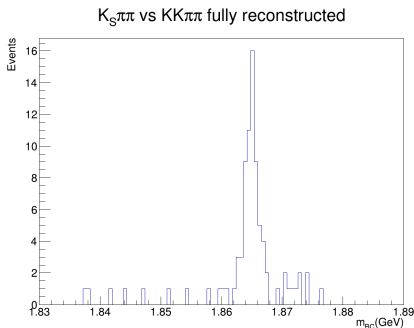
F_+ measurement with $K_S\pi\pi$ tag

- Solution: Partially reconstructed $KK\pi\pi$

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

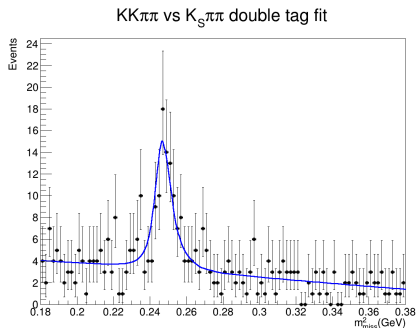| Mode	Inclusive yield	Double tag efficiency
$K_S\pi\pi$ (fully reconstructed)	67.2	6.63 ± 0.04
$K_S\pi\pi$ (partially reconstructed)	85.9	6.50 ± 0.03
$K_L\pi\pi$ (partially reconstructed)	176.9	7.29 ± 0.04

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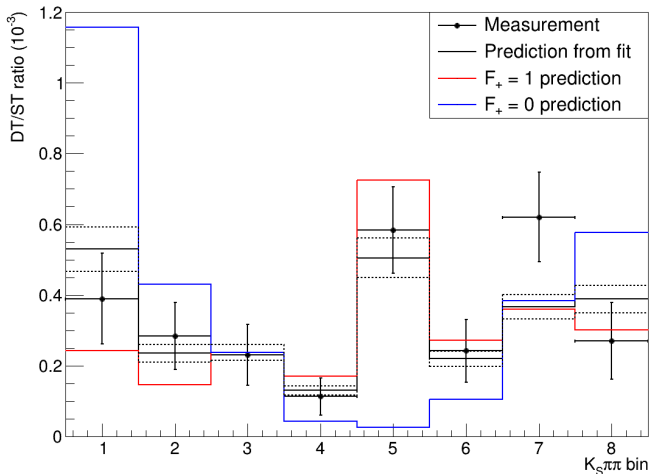- Require no π^0 candidates

(a) Fully reconstructed
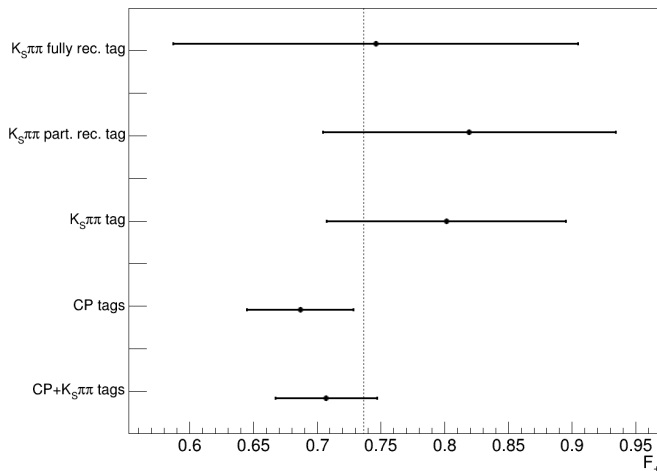

(b) Partially reconstructed

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

- Combine fully and partially reconstructed $KK\pi\pi$ vs $K_S\pi\pi$ to fit for F_+
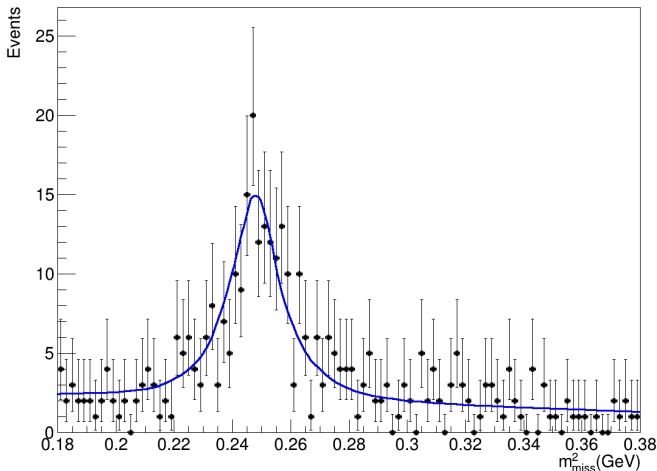
KK$\pi\pi$ vs K$_S\pi\pi$ double tag yields

Measurement of CP even fraction F_+ in $D \to KK\pi\pi$

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

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

KK$\pi\pi$ vs K$_L\pi\pi$ double tag fit

Summary

- LHCb $B^{\pm} \to (K^+ K^- \pi^+ \pi^-)_D h^{\pm}$ GGSZ+GLW analysis:
  - 2/3 reviewers have no further comments, waiting for final reply
  - Sign of s_i must be resolved

- BESIII $D \to K^+ K^- \pi^+ \pi^-$ 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!