Search for A_{CP} in $D^+_{(s)} \to \eta h^+$ & Br measurement in $D^+_{(s)} \to \eta K^+$ at Belle II

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Lab meeting

Introduction

Decays

- $D^+ \to \eta\pi^+$: Singly Cabibbo-suppressed (SCS)
- $D^+ \to \eta K^+$: Doubly Cabibbo-suppressed (DCS)
- $D_s^+ \to \eta\pi^+$: Cabibbo favoured (CF)
- $D_s^+ \to \eta K^+$: SCS
- Using both $\eta \to \gamma\gamma, \eta \to \pi^+\pi^-\pi^0$

Target measurements with Belle II data

- A_{CP} of $D_{(s)}^+ \to \eta h^+ (h = \pi, K)$
- Branch fraction of $D_{(s)}^+ \to \eta K^+$ normalized by $D_{(s)}^+ \to \eta\pi^+$

Experimental histories

Decay Mode	Experiment	A_{CP}	Br
$D^+ \to \eta\pi^+$ (SCS)	LHCb (2023)	$(0.34 \pm 0.66 \pm 0.16 \pm 0.05)\%$	-
	LHCb (2021)	$(0.13 \pm 0.50 \pm 0.18)\%$	-
	BESIII (2018)	-	$(37.90 \pm 0.70 \pm 0.68) \cdot 10^{-4}$
	Belle (2011, 791/fb)	$(1.74 \pm 1.13 \pm 0.19)\%$	-
	CLEO (2010)	$(-2.0 \pm 2.3 \pm 0.3)\%$	$(35.4 \pm 0.8 \pm 1.8 \pm 0.8) \cdot 10^{-4}$
$D^+ \to \eta K^+$ (DCS)	LHCb (2021)	$(-6 \pm 10 \pm 4) \cdot 10^{-2}$	-
	BESIII (2018)	-	$(0.151 \pm 0.025 \pm 0.014) \cdot 10^{-3}$
	Belle (2011, 791/fb)	-	$(1.08 \pm 0.17 \pm 0.08) \cdot 10^{-4}$
$D_s^+ \to \eta\pi^+$ (CF)	LHCb (2023)	$(0.32 \pm 0.51 \pm 0.12)\%$	-
	LHCb (2021)	$(0.8 \pm 0.7 \pm 0.5)\%$	-
	Belle (2021, 921/fb)	$(0.2 \pm 0.3 \pm 0.3)\%$	$(19.00 \pm 0.10 \pm 0.59 \pm 0.68) \cdot 10^{-3}$
			More experiments
$D_s^+ \to \eta K^+$ (SCS)	LHCb (2021)	$(0.9 \pm 3.7 \pm 1.1)\%$	-
	Belle (2021, 921/fb)	$(2.1 \pm 2.1 \pm 0.4)\%$	$(1.75 \pm 0.05 \pm 0.5 \pm 0.06) \cdot 10^{-3}$
	BESIII (2020)	-	$(1.62 \pm 0.10 \pm 0.03 \pm 0.05) \cdot 10^{-3}$

Target measurements: A_{CP} in all 4 modes, Br in 2 kaon modes($D^+_{(s)} \to \eta K^+$)

Analysis methodology

Basic ideas

- Direct reconstruction and fit to $M(\eta_{\gamma\gamma}h^+)$: no D^{*+} tagging
- Train BDT(XGboost) with grid search: $(\eta_{\gamma\gamma}, \pi^+), (\eta_{\gamma\gamma}, K^+), (\eta_{3\pi}, \pi^+), (\eta_{3\pi}, K^+)$
- BDT - signal: $D^+ \to \eta h^+$, bkg: $D_s^+ \to \eta h^+$ subtracted generic background
- BDT(XGboost) value is used to optimize

Branch fraction

- Ratio: $\frac{D^+_{(s)} \to \eta K^+}{D^+_{(s)} \to \eta \pi^+}$, expect to minimize systematics as Belle did

A_{CP}

- Plan: might use control modes, $D^+_{(s)} \to K^0_S h^+$ to correct $A_{\epsilon_{h^+}}$

Currently MC15ri(since MC15rd signals are now prepared)

Selection criteria

Before MVA,

Hard π^+: In CDC acceptance, dr<1, |dz|<3, $L_\pi > 0.6$
π^+: In CDC acceptance, dr<1, |dz|<3, $L_\pi > 0.1$
Hard K^+ : In CDC acceptance, dr<1, |dz|<3, $L_K > 0.6, L_\pi < 0.01$
γ for η: clusterNHits>1.5, 0.2967< clusterTheta<2.6180, E>0.1
γ for π^0: clusterNHits>1.5, 0.2967< clusterTheta<2.6180, E>0.055,
beamBackgroundSuppression > 0.5, fakePhotonSuppression > 0.1

π^0 for η: 0.12<M<0.145, -1.5<daughterDiffOfPhi(0,1)<1.5, daughterAngle(0,1)<1.4
$\eta_{\gamma\gamma}$: 0.52 < M < 0.57, p > 0.4 GeV
$\eta_{3\pi}$: 0.535 < M < 0.57, p>0.4 GeV

D^+: $p_{CMS} > 2.5$, treefit chiProb > 0.001 (π^0, η mass constraint)

particles	selection criteria
γ_{ROE}	$\lvert\text{clusterTiming}\rvert < 200ns$ $\lvert\frac{\text{clusterTiming}}{\text{clusterErrorTiming}}\rvert < 2.0$ clusterNHits> 1.5 $E > 55$MeV beamBackgroundSuppression > 0.5 fakePhotonSuppression > 0.1

particles	selection criteria
$\lvert M(\gamma\gamma_{ROE}) - m_{\pi^0}\rvert$	$> 0.011\text{GeV/c}^2$

MVA(BDT) study

Trained BDTs among different final states:$(\eta_{\gamma\gamma}, \pi^+), (\eta_{\gamma\gamma}, K^+), (\eta_{3\pi}, \pi^+), (\eta_{3\pi}, K^+)$

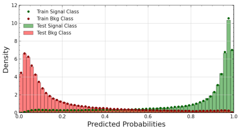
Train variables

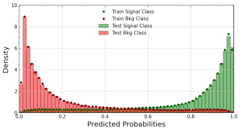
- $D^+_{(s)} \to \eta_{\gamma\gamma} h^+$: 6 variables
  $dr(\pi^+), \cos\theta_{XY}(D^+), |\frac{E_{\gamma_1} - E_{\gamma_2}}{E_{\gamma_1} + E_{\gamma_2}}|,$
  $\Delta\phi(\gamma_1, \gamma_2), p(\eta) + p(\pi^+),$
  cosHelicityAngleMomentum(D^+)
- $D^+_{(s)} \to \eta_{3\pi} h^+$: 4 variables
  $dr(\pi^+), \cos\theta_{XY}(D^+),$
  $p(\eta) + p(\pi^+),$
  cosHelicityAngleMomentum(D^+)

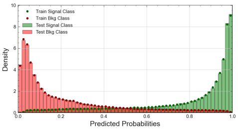
No significant correlations(in backup slides)

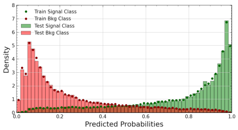
Performed grid search

$D^+ \to \eta_{\gamma\gamma}\pi^+, D^+ \to \eta_{3\pi}\pi^+, D^+ \to \eta_{\gamma\gamma}K^+, D^+ \to \eta_{3\pi}K^+$



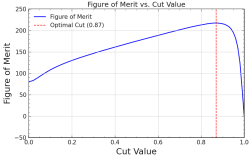


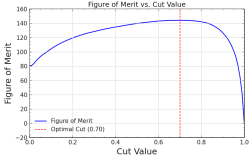


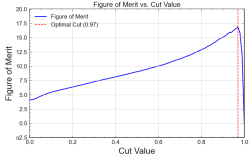


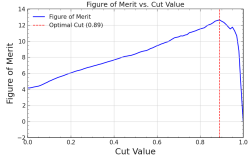
Cut optimization

Optimized variable: BDT in D^+ signal region(might not be optimal to D_s^+)
$D^+ \to \eta_{\gamma\gamma}\pi^+, D^+ \to \eta_{3\pi}\pi^+, D^+ \to \eta_{\gamma\gamma}K^+, D^+ \to \eta_{3\pi}K^+$

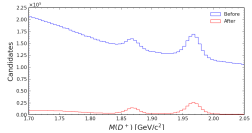


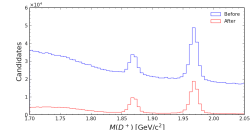


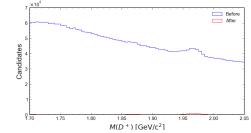


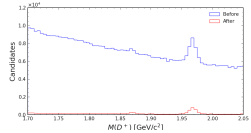


Before vs. after cut



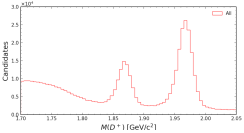


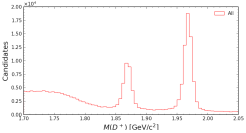


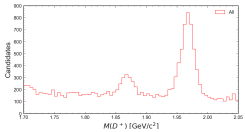


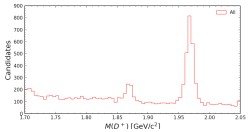
Distribution & Signal efficiency

$D^+ \to \eta_{\gamma\gamma}\pi^+, D^+ \to \eta_{3\pi}\pi^+, D^+ \to \eta_{\gamma\gamma}K^+, D^+ \to \eta_{3\pi}K^+$









Signal efficiency(%)

Mode	Belle II	Belle (2011)	Belle (2021)
$D^+ \to \eta_{\gamma\gamma}K^+$	3.42 ± 0.01		
$D^+ \to \eta_{\pi\pi\pi}K^+$	3.28 ± 0.01	1.35 ± 0.01	
$D_s^+ \to \eta_{\gamma\gamma}K^+$	2.04 ± 0.01		7.42 ± 0.05
$D_s^+ \to \eta_{\pi\pi\pi}K^+$	2.02 ± 0.01		4.04 ± 0.02
$D^+ \to \eta_{\gamma\gamma}\pi^+$	8.85 ± 0.02		
$D^+ \to \eta_{\pi\pi\pi}\pi^+$	6.17 ± 0.02	1.68 ± 0.02	
$D_s^+ \to \eta_{\gamma\gamma}\pi^+$	7.54 ± 0.02		10.84 ± 0.02
$D_s^+ \to \eta_{\pi\pi\pi}\pi^+$	5.29 ± 0.02		6.50 ± 0.03

Fitting

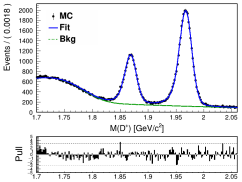
Simultaneous fit($D^+_{(s)} + D^-_{(s)}$)

- Set fitting range to cover D^+ and D^+_s

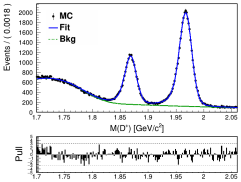
Fit method

- Signals: $D^+_{(s)} \to \eta h^+$
  - MC fixed: double-sided cystall ball
  - Floating: gaussian
- Backgrounds
  - $M(\eta\pi^+)$: $D^+_s \to (\rho^+ \to \pi^+\pi^0)\eta$, fixed with Novosibirsk function
  - Other combinatorial
    - $M(\eta\pi^+)$: exponential
    - $M(\eta K^+)$: 2nd order Chebyshev

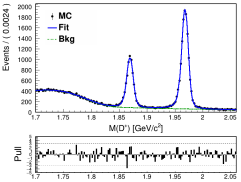
Fit result



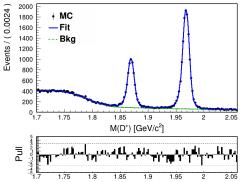
(a) $M(\eta_{\gamma\gamma}\pi^+)$



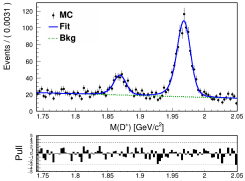
(b) $M(\eta_{\gamma\gamma}\pi^-)$



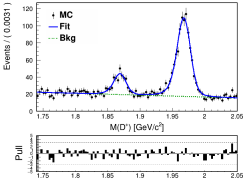
(e) $M(\eta_{3\pi}\pi^+)$



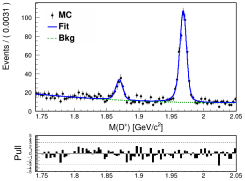
(f) $M(\eta_{3\pi}\pi^-)$



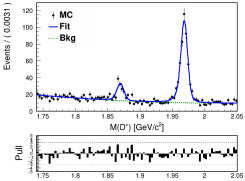
(c) $M(\eta_{\gamma\gamma}K^+)$



(d) $M(\eta_{\gamma\gamma}K^-)$

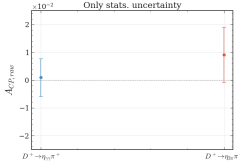


(g) $M(\eta_{3\pi}K^+)$

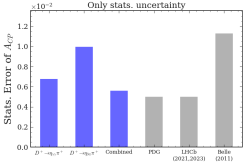


(h) $M(\eta_{3\pi}K^-)$

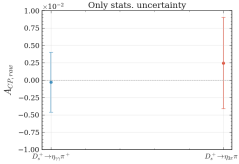
Acp fit result



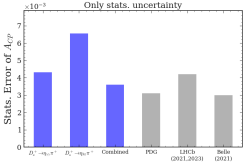
(a) $A_{CP,raw}(D^+ \to \eta\pi^+)$



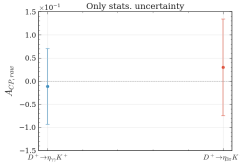
(b) Stat. unc.



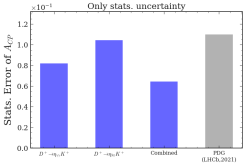
(e) $A_{CP,raw}(D_s^+ \to \eta\pi^+)$



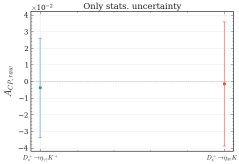
(f) Stat. unc.



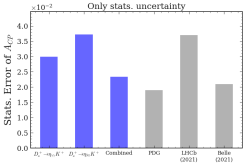
(c) $A_{CP,raw}(D^+ \to \eta K^+)$



(d) Stat. unc.

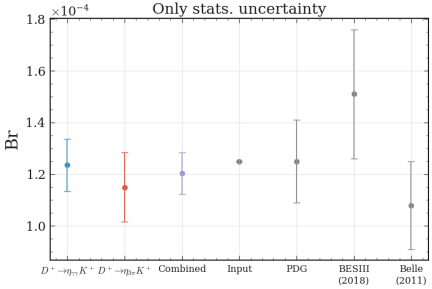


(g) $A_{CP,raw}(D_s^+ \to \eta K^+)$

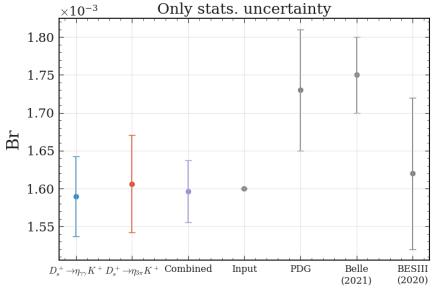


(h) Stat. unc.

Branch fraction fit result



(a) $D^+ \to \eta K^+$



(b) $D_s^+ \to \eta K^+$

To normalize with $\frac{D_{(s)}^+ \to \eta K^+}{D_{(s)}^+ \to \eta \pi^+}$, BDTs trained by $D^+ \to \eta_{\gamma\gamma} K^+, D^+ \to \eta_{3\pi} K^+$ are applied to normalized channels($D^+ \to \eta_{\gamma\gamma}\pi^+, D^+ \to \eta_{3\pi}\pi^+$)

A_{CP} control modes

Candidates of A_{CP} control modes(PDG values)

Mode	A_{CP}	Br
$D^+ \to K^0_S\pi^+$	-0.0041 ± 0.0009	$(1.562 \pm 0.031)\%$
$D^+_s \to K^0_S\pi^+$	0.0020 ± 0.0018	$(1.09 \pm 0.05) \cdot 10^{-3}$
$D^+ \to K^0_S K^+$	-0.0001 ± 0.0007	$(3.04 \pm 0.09) \cdot 10^{-3}$
$D^+_s \to K^0_S K^+$	0.0009 ± 0.0026	$(1.450 \pm 0.035)\%$

$A_{raw} \approx A_{CP} + A_{FB} + A_{\epsilon^+_h}$
$A_{raw,ref} \approx A_{CP,ref} + A_{FB,ref} + A_{\epsilon^+_h,ref}$
$A_{CP} = A_{CP,raw} + A_{raw} - A_{raw,ref}$
To make sure to cancel out, A_{FB}: $cos\theta_{CM}(D^+)$
$A_{\epsilon^+_h}$: $cos\theta(h^+), p(h^+)$

Summary & Plans

Summary

Using MC15ri samples,

- Estimation of stats. unc. of A_{CP} for $D^+_{(s)} \to \eta h^+$ in 427.87/fb
  - $h = \pi$: comparable stats. unc. with previous measurements
  - $h = K$: could improve PDG value
- Estimation of stats. unc. of $Br(D^+_{(s)} \to \eta K^+)$ in 427.87/fb

  In terms of stats. unc.,
  - $Br(D^+ \to \eta K^+)$: could improve PDG value
  - $Br(D^+_s \to \eta K^+)$: comparable result with Belle(2021, 921/fb)

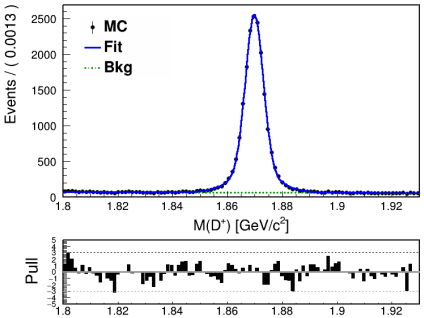
Plans

- Move to MC15rd samples(my signals are ready)
- A_{CP} control sample study: might use $D^+ \to K^0_S h^+$

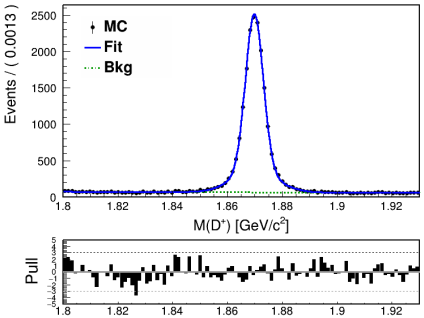
Several comments

- Have considered to optimize photon MVA variables() and PIDNN(neural network PID) ?
- New data(part of Run2, 50/fb) is availble, how about to add?
- $D^+ \to K_0^S \pi^+$: one is already using as control channel for $D^+ \to \pi^+ \pi^)$ A_{CP} study

$D^+ \to K^0_S K^+$

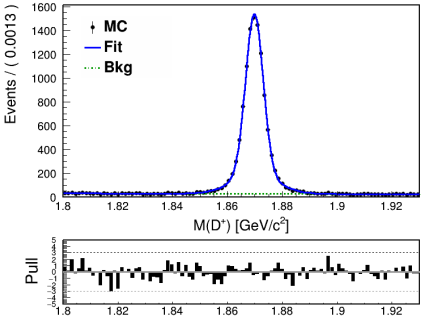


(a) $D^+ \to \eta_{3\pi} K^+$

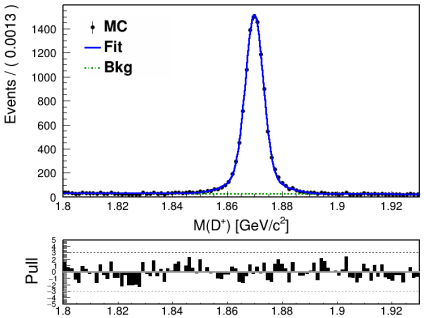


(b) $D^- \to \eta_{3\pi} K^-$

$D^+ \to K^0_S K^+$

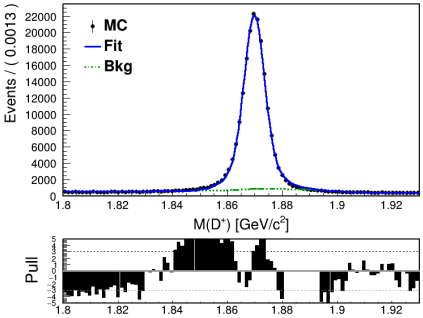


(a) $D^+ \to \eta_{\gamma\gamma}\pi^+$

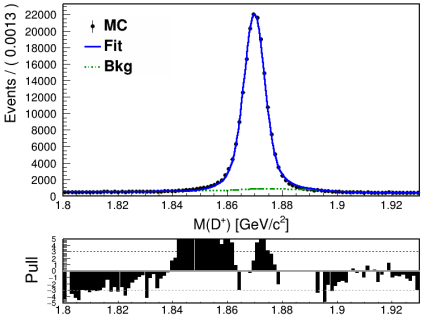


(b) $D^- \to \eta_{\gamma\gamma}\pi^-$

$D^+ \to K^0_S \pi^+$

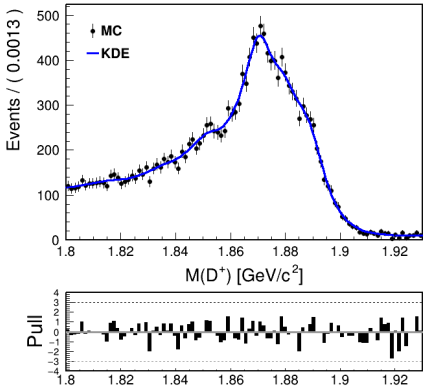


(a) $D^+ \to \eta_{3\pi}\pi^+$

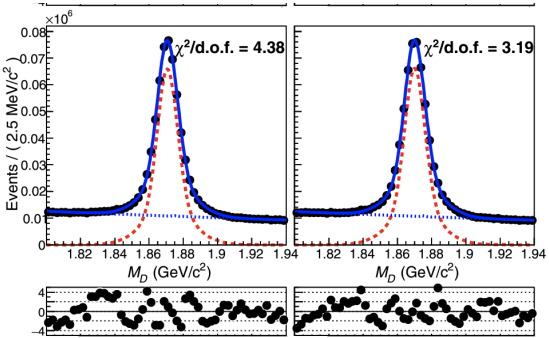


(b) $D^- \to \eta_{3\pi}\pi^-$

$D^+ \to K^0_S \pi^+$

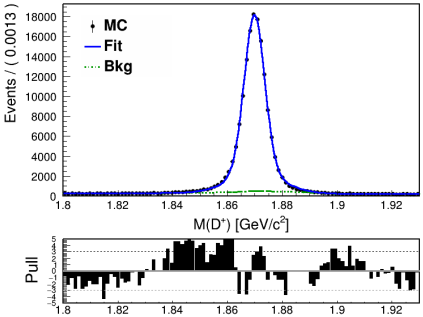


(a) Generic MC

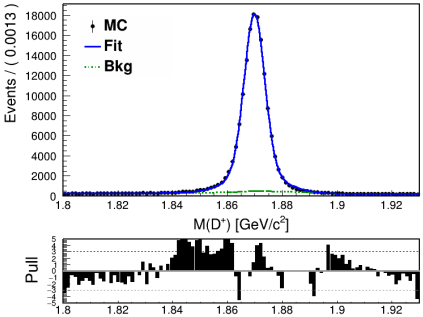


(b) $D^+ \to \pi^+\pi^0$ study at Belle

$D^+ \to K^0_S \pi^+$



(a) $D^+ \to \eta_{\gamma\gamma} K^+$

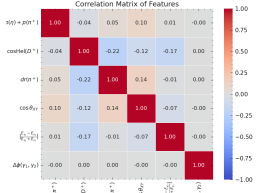


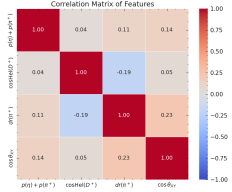
(b) $D^- \to \eta_{\gamma\gamma} K^-$

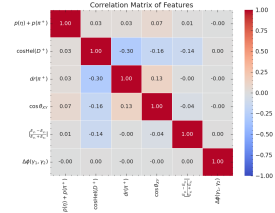
Backup

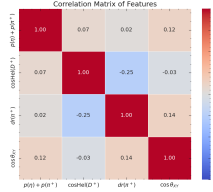
BDT

Variable correlations $D^+ \to \eta_{\gamma\gamma}\pi^+, D^+ \to \eta_{3\pi}\pi^+, D^+ \to \eta_{\gamma\gamma}K^+, D^+ \to \eta_{3\pi}K^+$









Variable importance