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Amplitude analysis of $D_s^+ \to K^+K^-\pi^+$

Meng Wang[a], Yu Lu[a], and Liaoyuan Dong[a], and Huaimin Liu[a]

[a]*Institute of High Energy Physics, CAS*

Internal Referee Committee

Ref1 xx (Chair)[d], Ref2 xx[e], and Ref3 xx[f]

[d]*Department of Computer Science and Engineering*
[e]*Department of Electrical Engineering*
[f]*Latex Univeristy*

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Abstract

We have performed an amplitude analysis of $D_s^+ \to K^+K^-\pi^+$ using a data sample of $3.19 fb^{-1}$ recorded with BESIII detector at 1.178GeV. 4265 events with about %0.5 background are used in this analysis. There are 6 intermediate resonances in the model which does the best fit to data. Especially, $a_0(980) - f_0(980)$ mixing is taken in account in the model.

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1 Introduction

The decay $D_s^+ \to K^+K^-\pi^+$ is a Cabibbo-favored (CF) channel and has a large branching fraction for the D_s meson. Thus, this decay channel is usually used to normalize measurements of decay chains involving charm quarks.

Knowledge of the decay amplitude allows us to properly account for interference effects when measuring absolute hadronic branching fractions of D_s mesons.

Below is the table of previous analyses of this decay channel.

	Decay fraction (%)		
Decay mode	*BABAR*	E687	CLEO-c
$\bar{K}^*(892)^0K^+$	$47.9 \pm 0.5 \pm 0.5$	$47.8 \pm 4.6 \pm 4.0$	$47.4 \pm 1.5 \pm 0.4$
$\phi(1020)\pi^+$	$41.4 \pm 0.8 \pm 0.5$	$39.6 \pm 3.3 \pm 4.7$	$42.2 \pm 1.6 \pm 0.3$
$f_0(980)\pi^+$	$16.4 \pm 0.7 \pm 2.0$	$11.0 \pm 3.5 \pm 2.6$	$28.2 \pm 1.9 \pm 1.8$
$\bar{K}_0^*(1430)^0K^+$	$2.4 \pm 0.3 \pm 1.0$	$9.3 \pm 3.2 \pm 3.2$	$3.9 \pm 0.5 \pm 0.5$
$f_0(1710)\pi^+$	$1.1 \pm 0.1 \pm 0.1$	$3.4 \pm 2.3 \pm 3.5$	$3.4 \pm 0.5 \pm 0.3$
$f_0(1370)\pi^+$	$1.1 \pm 0.1 \pm 0.2$	$\cdots$	$4.3 \pm 0.6 \pm 0.5$
Sum	$110.2 \pm 0.6 \pm 2.0$	111.1	$129.5 \pm 4.4 \pm 2.0$
χ^2/NDF	$\frac{2843}{(2305-14)} = 1.2$	$\frac{50.2}{33} = 1.5$	$\frac{178}{117} = 1.5$
Events	96307 ± 369	701 ± 36	12226 ± 22

Figure 1: previous analyses

From figure.1 [1], we can see an obvious difference of decay fraction of $f_0(980)\pi^+$ between BARBAR and CLEO-c. E687 used about 700 events and the E687 model did not take $f_0(1370)\pi^+$ into account. For CLEO-c, about 14400 events with purity about 84.9% were selected with single tag method. The analysis of BARBAR used about 100000 events with purity about 95%. In this analysis with double tag method, we can get a nearly background free data sample, that will be good to perform the amplitude analysis.

2 Data Set and Monte Carlo Samples

We use 3.195 fb^{-1} data set collected at $E_{cm} = 4.178GeV$ by BESIII detector in 2016. Both data sample and Monte Carlo samples are reconstructed under BOSS7.0.3. Totally 35 rounds of generic MC with each round equaling to data size are used for background study. They are avaulable at /besfs3/offline/data/703-1/4180/mc/.

For the Signal MC, we generate the signal events with one D_s decaying to signal mode using the generator "DIY", in which the parameters are obtained from the fit to data. PHSP MC and Signal MC are used in MC integration required for the amplitude fit. The Signal MC is also used in the input/output check.

Table 1: Component and corresponding size, assume luminosity = 3195/pb.

Component	cross section (pb)	Size(M)	directory
D^0D^0	179	0.5719	D0D0
D^+D^-	197	0.6294	DpDm
$D^{*0}D^0$	1211	3.8691	DST0D0
$D^{*+}D^-$	1296	4.1407	DSTpDm
$D^{*0}D^{*0}$	2173	6.9427	DST0DST0
$D^{*+}D^{*-}$	2145	6.8533	DSTpDSTm
$D_s^+D_s^-$	7	0.0225	DsDs
$D_s^{*+}D_s^-$	961	3.0700	DsSTDs
$DD^*\pi^+$	383	1.2237	DDSTPIp
$DD^*\pi^0$	192	0.6134	DDSTPI0
$DD\pi^+$	50	0.1598	DDPIp
$DD\pi^0$	25	0.0799	DDPI0
Component	cross section (nb)	Size(M)	
$q\bar{q}$	13.8	44.0910	qq
$\gamma J/\psi$	0.40	1.2780	RR1S
$\gamma\psi(2S)$	0.42	1.3419	RR2S
$\gamma\psi(3770)$	0.06	0.1917	RR3770
$\tau\tau$	3.45	11.0228	tt
$\mu\mu$	5.24	16.7418	mm
ee	423.99	13.5465(0.01×)	ee
$\gamma\gamma$	1.7	5.4315	TwoGam
HCT	0.10178	0.3252	HCT

Table 2: Component and corresponding observed cross section (output from ConExc) for charmonium hadronic transition (HCT) processes.

Mode index	Final state	Observed cross section @ 4180 MeV (nb)	Referee of input line shape
79	$\pi^0\pi^0\psi(2S)$	0.00342491	BELLE PRL99, 142002 (2007)
91	$\pi^+\pi^-\psi(2S)$	0.00684981	BELLE PRL99, 142002 (2007)
80	$\eta J/\psi$	0.0321958	BELLE PRD87, 051101(R) (2013)
81	$\pi^+\pi^-h_c$	0.0122136	BESIII PRL111,242001 (2013)
82	$\pi^0\pi^0h_c$	0.00610681	BESIII PRL111,242001 (2013)
83	K^+K^-J/ψ	0.000671349	BELLE PRD77, 011105(R) (2008)
84	$K_S^0K_S^0J/\psi$	0.000167837	BELLE PRD77, 011105(R) (2008)
90	$\pi^+\pi^-J/\psi$	0.026767	BELLE PRL99, 182004 (2007)
99	$\pi^0\pi^0J/\psi$	0.0133835	BELLE PRL99, 182004 (2007)
sum		0.101780616	

3 Event Selection

At $E_{cm} = 4.178 GeV$, pairs of $D_s D_s^*$ are produced, and the D_s^* decays to either $D_s\gamma$ or $D_s\pi^0$. We use double tag method to select our signal events.

3.1 Tracking, PID, $\pi^0/\eta^{(')}$ and K_S^0 Rconstruction

D_s candicates are built from $K^\pm$, $\pi^\pm$, $\pi^0/\eta^{(0)}$ and K_S^0. The selections of the particles to build D_S candicates are performed with DTagAlg-00-01-05 package with the default setting, which are summarized below.

- Tracking:
  - The properties of charged tracks are determined based on the MDC information. Charged track candidates must satisfy:
    - $|cos\theta| < 0.93$.
    - $|dr| < 1cm$ and $|dz| < 10cm$, where $|dr|$ and $|dz|$ are defined as the one reconstructed minus the interaction point.
- Particle ID:
  - Charged tracks are identified as pion or kaon with Particle Identification (PID), which is implemented by combing the information of the energy loss (dE/dx) in MDC and the time-of-flight measured from the TOF system. Kaon and Pion are identified with the requirements that
    - *Prob(K)* > 0.00 and *Prob(K)* $>$ *Prob(π)* for K,
    - *Prob(π)* > 0.00 and *Prob(π)* $>$ *Prob(K)* for π, where *Prob(X)* is the probability of hypothesis X, X can be π or K.
- π^0/η selection: π^0 candidates are reconstructed through $\pi^0 \to \gamma\gamma$ with package of PioEtaToGGRecAlg. The photons are reconstructed as energy showers on the EMC. We require:
  - Minimum energy for barrel showers($|cos\theta| < 0.8$): $E_{min} > 25MeV/c^2$,
  - Minimum energy for endcap showers($0.86 < |cos\theta| < 0.92$): $E_{min} > 50MeV/c^2$,
  - Shower within other $|cos\theta|$ regions are rejected.
  - EMC time requirements for events with at least one charged track detected: $0 \leq t \geq 14$(50ns),

  Then we perform a constrained fit on the photon pairs to the nominal π^0/η mass and require:

- The unconstrained invariant mass for π^0: $0.115 < M(\gamma\gamma) < 0.015GeV/c^2$,
- The unconstrained invariant mass for η : $0.490 < M(\eta) < 0.580GeV/c^2$,
- Mass fit: $\chi^2_{1c} < 30$.

- η' selection: The η' candidates are reconstructed with $\pi^+\pi^-\eta$, the invariant mass for $\pi^+\pi^-\eta$ is required to fall into the range of $[0.938, 0.978]GeV^2$.

- K^0_S selection: K^0_S candidates are reconstructed using VeeVertexAlg package with two opposite charged tracks with requiring:
  - $|cos\theta| < 0.93$
  - $|dz| < 20cm$

  For each pair of tracks, a constrained vertex fit is performed and the track parameters' results are used to get the invariant mass $M(K^0_S)$. Then the decay length of K^0_S is obtained with second vertex fit by the SecondVertexFit package. For K^0_S selection, we require:
  - $0.487GeV/c^2 < M(K^0_S) < 0.511GeV/c^2$.
  - Significance of the K^0_S decay lenght has two standard deviations.

- D_s selection: According to the MC study on D_s reconstruction (BESSIII-DocDB-380), the D_s candidates fall into the mass window of $1.90 < m_{D_s} < 2.03GeV/c^2$ and the corresponding M_{rec} satisfied $2.051 < M_{rec} < 2.180GeV/c^2$ are retained for further study. In which, the definition of M_{rec} is

$$M_{rec} = \sqrt{(E_{cm} - \sqrt{p^2_{D_s} + m^2_{D_s}})^2 - |\vec{p}_{cm} - \vec{p}_{D_s}|^2}\ , \quad (1)$$

  where E_{cm} is the energy of initial state, calculated from the beam energy [2], $\vec{p}_{D_s}$ is the momentum of D_s candidate, m_{D_s} is D_s mass quoted from PDG [3] and $\vec{p}_{cm}$ and $\vec{p}_{D_s}$ are four-momentum of initial state and the decay products of a D_s candidate, respectively.

3.2 Single Tag Selection

As D^+_s and D^-_s should appear in pairs, so we can use double tag method to select signal events. After $K^\pm$, K^0_S, $\pi^\pm$ and γ are identified, hadronic D_s decays can be reconstructed with the DTag package. 8 tag modes are used:

$D^-_s \to K^+K^-\pi^-$, $D^-_s \to K^0_S K^-$, $D^-_s \to K^0_S K^-\pi^+\pi^-$, $D^-_s \to K^-\pi^+\pi^-$, $D^-_s \to K^0_S K^+\pi^-\pi^-$, $D^-_s \to \pi^+\pi^-\pi^-$, $D^-_s \to \eta'_{\pi^+\pi^-\eta_{\gamma\gamma}}$, $D^-_s \to K^+K^-\pi^-\pi^0$.

Before selecting the best candidate, we vote the candidates with $\pi^{\pm}(\pi^0)$ whose momentum is less than $0.1GeV$ to remove soft $\pi^{\pm}(\pi^0)$ from D^* decays.

For every candidate of D_s decays, all tracks at signal side and tag side as well as gamma from D_s^* are added to apply kinematic fitting. 5 constrains are added in kinematic fitting: four-momentum of $D_sD_s^*$, mass of D_s^*. Then we select the candidate with minmimum χ^2_{5c}.

The candidates satisfy:

- $1.95GeV < m_{sig} < 1.985GeV$
- $1.95GeV < m_{tag} < 1.985GeV$
- $\chi^2_{5c} < 50$

are retained for amplitude analysis, where m_{sig} and m_{tag} refer to mass of D_s at signal side and tag side respectively.

3.3 Background Analysis

We use generic MC to estimate the background. The background and signal shape of generic MC is shown in Fig.2. According to the luminosities of the data and the generic MC, after scaling the background sample to the data size, the background yiels in Signal region is 11.8. Then the fit to the signal D_s invariant mass (m_{sig}) spectrum gives the background yield in Signal region is 11.3 ± 3.9, shown as in Fig.3. The background level in MC is then consistent with the data. In the fit, the signal shape is the MC shape convoluted with a Gaussian function and the background is the MC shape.

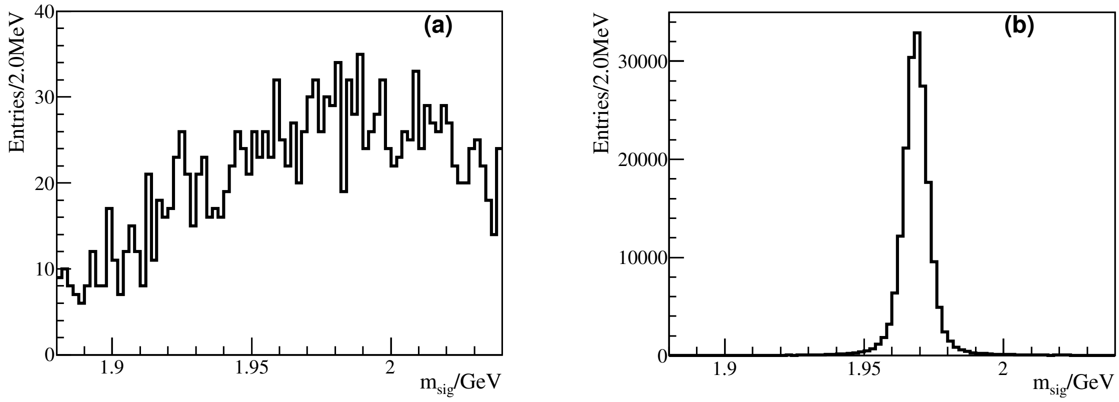

Figure 2: The background (a) and signal (b) distributions from generic MC after selection

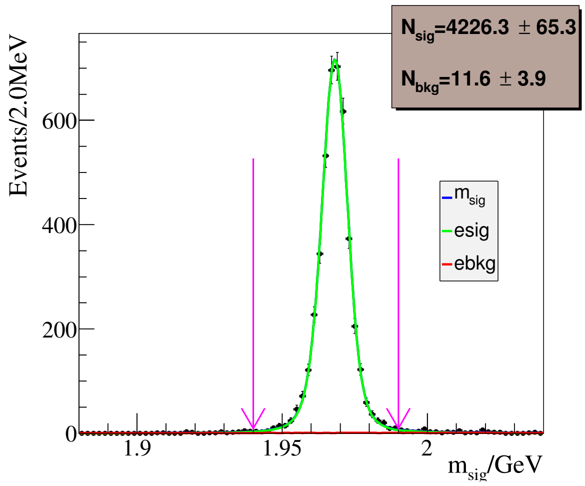

Figure 3: The fit to m_{sig} for data after selections, the area between the purple arrows is the signal area of the sample for the amplitude analysis.

4 Amplitude Analysis

Amplitude Analysis

5 Summary

Summary

References

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[2] Andy Julin, Hajime Muramatsu and Ron Poling, BESIII DocDB 580-v1.

[3] C. Patrignani *et al.* (Paritcle Data Group), Chin. Phys. C 40,100001 (2016)

Appendices

A Substract of the Secondary proton

A sizable of (anti-)proton candidates are produced from the electron/positron beam or particles in final states interacting with the MDC inner wall or residual gas inside beam-pipe, especially for proton. Here, we take the decay mode $\Lambda_c^+ \to p\eta(\gamma\gamma)$ as an example. Fig. **??** shows the compared V_{r} distributions of proton and anti-proton in different samples. In this analysis, we use the scaled inclusive MC to optimize the tight requirement with the $/\sqrt{S+B}$ curve. Fig. **??** shows the efficiency distribution and $S/\sqrt{S+B}$ distribution with different V_{r} requirement. Where, S represents signal events, and B is scaled inclusive MC sample.