Amplitude analysis of $D^+ \to \pi^+\eta K_S$ *and* $K^+K_SK_S$

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Motivation

A) What's $a_0(980)$?

- ✓ Quark-antiquark pairs?
- ✓ Diquark-antidiquark pairs?
- ✓ molecular?

B) Two channels constrain each other

- ✓ Help to study the couple of $\pi\eta$ and KK channels

The charge-conjugate channel is implies in this analysis

Method

A) Iso-bar model for amplitude analysis

- ✓ Each process can be decomposed into $A \to BC$
- ✓ Amplitude

$$\mathcal{A}(L, l, m_{ab}, m_{bc}) = \Sigma_i Y(L, l, p, q) B_L^D(p) B_l^R(q) T_R(m_{ab}) \tag{1}$$

- ✓ PDF: the MC is the MC sample that pass all event selection requirement

$$S(p) = \frac{1}{C} \sum_{MC} |\mathcal{A}|^2 \tag{2}$$

- ✓ likelihood

$$ln\mathcal{L} = \sum_{data} lnS - weight \cdot \sum_{bkg} lnS \tag{3}$$

$\pi^+\eta K_S$ channel

Event Selection

I) Good charged track
- ✓ Vertex: $V_r < 1\ cm$, $V_z < 10\ cm$
- ✓ Polar angle: $cos\theta < 0.93$

II) Good photons
- ✓ Barrel: $cos\theta < 0.8$, $E_\gamma > 25$ MeV
- ✓ End Cap: $0.86 < cos\theta < 0.92$, $E_\gamma > 50$ MeV

III) PID: SimplePIDSvc

IV) π^0 candidates
- ✓ $\chi^2 < 200$
- ✓ $[115, 150]$ MeV$/c^2$

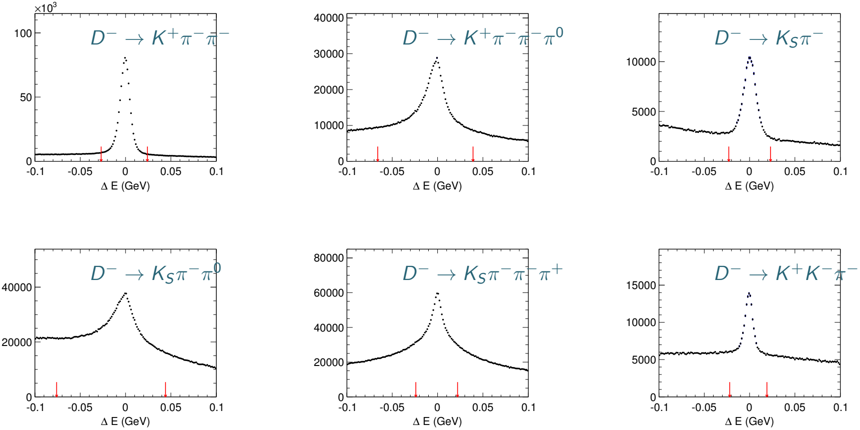
V) K_S^0 candidates
- ✓ $\chi^2 < 100$
- ✓ $[0.487, 0.511]$ GeV$/c^2$

VI) η candidates
- ✓ $M(\eta) \sim [0.47, 0.57]$ GeV
- ✓ $\chi^2_{1C} < 40$

VII) Select best tag D^- candidate:
- ✓ $|E_{D^-} - E_{beam}| = min$

Requirement on ΔE

- ✓ $\Delta E = E(D^-) - E(beam)$
- ✓ The ΔE is required in rangre $[-3\sigma, 3\sigma]$

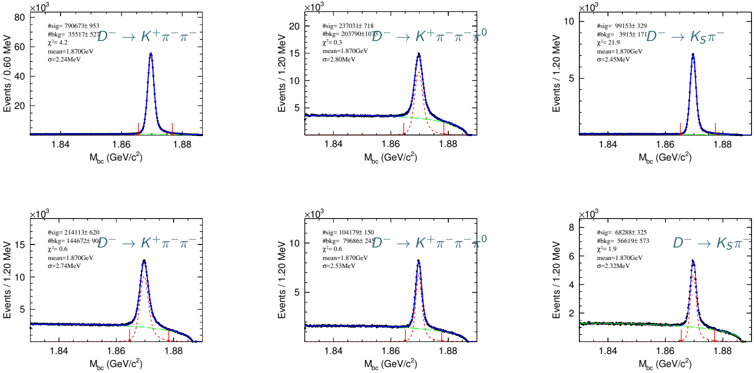


Tag Yields

A) Model

- ✓ MC shape $\otimes$ **Gaus** + Argus

B) signal region:$[-2\sigma, 3\sigma]$



Search for Signal

D^+ *Candidates*

A) Select best candidate: $\chi^2_{3C} = min$

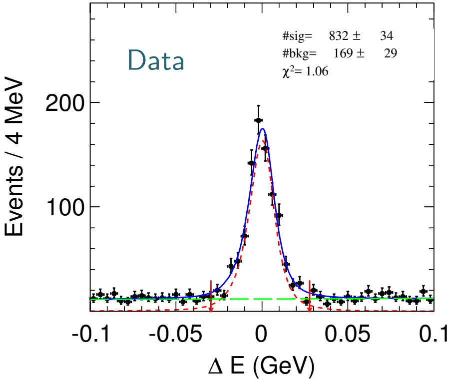
✓ Constrain the energy, $M(\pi\pi)$ and $M(2\gamma)$

$$\chi^2 \sim \left(\frac{\Delta E}{\sigma_{\Delta E}}\right)^2 + \left(\frac{M(\pi\pi) - m_{K_S}}{\sigma_{K_S}}\right)^2 + \left(\frac{M(2\gamma) - m_\eta}{\sigma_{2\gamma}}\right)^2 \quad (4)$$

Requirement on ΔE

A) Model

- ✓ Double Gaus $\otimes$ **Gaus** + 2nd Chebychev
- ✓ **Double Gaus** shape are fixed according to the parameters of MC.

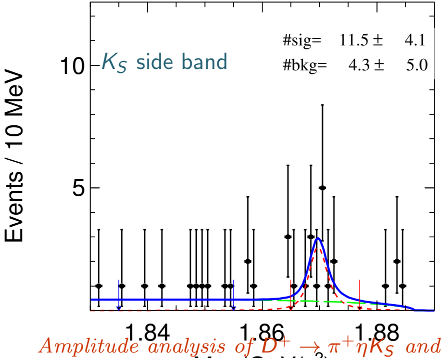


Background

A) Source

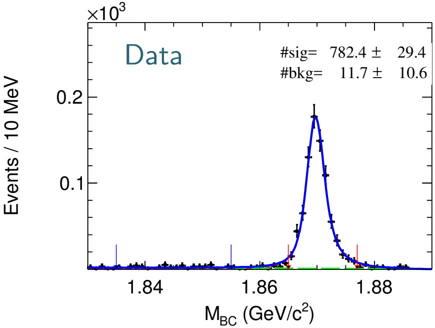
- ✓ Miscombination between K_S and π^+
- ✓ $\pi^+\eta'$
- ✓ $2\pi^+\pi^-\eta$

B) The peak background are estimated in K_S^0 side band



Data

- ✓ MC shape $\otimes$ **Gaus** + Argus
- ✓ 782 Events for Dalitz plot analysis
- ✓ Purity: 97%



Amplitude Analysis

Resonance candidates

A) $\pi^+\eta$

- ✓ $a_0(980)^+$, $a_0(1450)^+$, $a_2(1320)^+$, $\pi_1(1400)^+$

B) $K_S\eta$

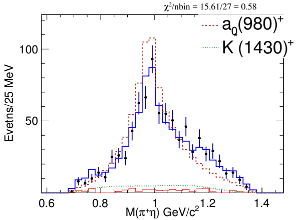
- ✓ $\bar{K}_0^*(1430)$, $\bar{K}_2(1580)$, $\bar{K}_1(1270)$

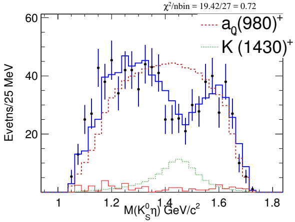
C) Line shape

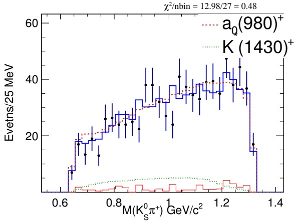
- ✓ $a(980)$: Flatte formalism PhysRevD.95.032002
- ✓ $K^*(1430)$
  - ✓ RBW
  - ✓ Alternative: Flatte formalism
- ✓ Others
  - ✓ RBW

Preliminary result

- ✓ Drop all resonances with significance less than 5 σ
- ✓ $a_0(980)^+$ + $K^{*0}(1430)$

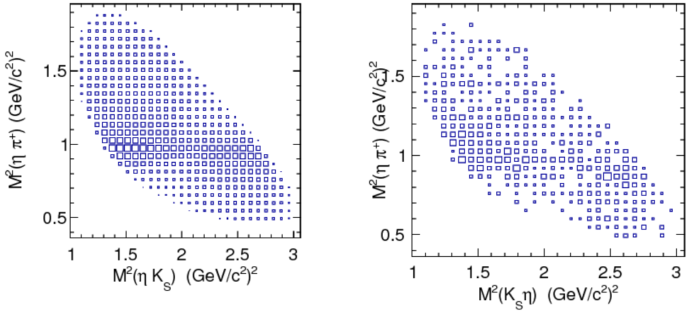






Compare

✓ The interference between a_0 and $K^*(1430)$ makes a dip.



Preliminary result

Final state	FF %	Phase
$a^+(980)K_S^0$	106.2 ± 0.9	0.
$K_0^*(1430)\pi^+$	10.4 ± 1.6	162 ± 5
Sum	116.4 ± 1.9	-

Systematic Uncertainty

✓ Main Uncertainty

source	$FF(a_0)$ (%)	$FF(K^*(1430))$ (%)
$a_0(980)$ parameters	1.2	1.0
$K^*(1430)$ parameters	1.0	7.7
background	0.02	2.5
fit bias	0.1	0.2

$Br(D^+ \to K_S\pi^+\eta)$

tag	DT yield	ϵ^{ST}	$\epsilon^{DT}/\epsilon^{ST}$
$D^- \to K^+\pi^-\pi^-$	649 ± 27	51.39 ± 0.02	10.3 ± 0.1
$D^- \to K_S\pi^-$	87 ± 10	50.82 ± 0.05	7.75 ± 0.02
$D^- \to K^+K^-\pi^-$	67 ± 9	42.60 ± 0.06	9.76 ± 0.28

$$Br(D^+ \to K_S\pi^+\eta) = (1.18 \pm 0.05 \pm 0.04)\% \quad (5)$$

Uncertainty

source	Uncertainty (%)
PID	0.5 [1]
Tracking	0.5 [1]
K_S^0 reconstruction	1.5 [2]
η reconstruction	2
M_{BC} fit	0.7
ΔE requirement	0.27
Cite BF	1.2
model	1.5
sum	3.4

Short Summary

A) The preliminary amplitude result is obtained

B) Obtain the absolution BF for$D^+ \to K_S \pi^+ \eta$

$$Br(D^+ \to K_S \pi^+ \eta) = (1.18 \pm 0.05 \pm 0.04)\% \tag{6}$$

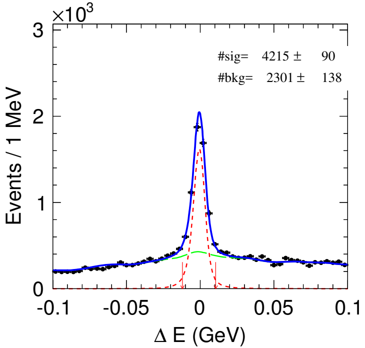
$K^+ K_S K_S$ channel

requirement on ΔE

A) Best D^+ candidate $\Delta E = min$

B) Model

- ✓ Double Gaus $\otimes$ **Gaus** + Shape in M_{BC} side band
- ✓ **Double Gaus** are fixed according to the parameters of MC.

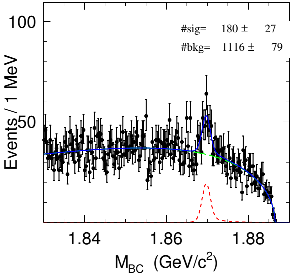


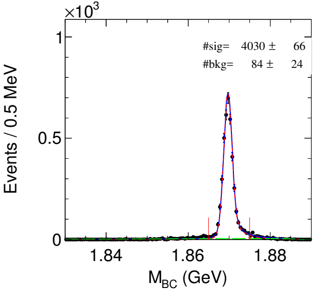
Signal Yield

A) **Peak**: estimated from K_S side band

B) model

✓ MC Shape $\otimes$ **Gaus** + Argus





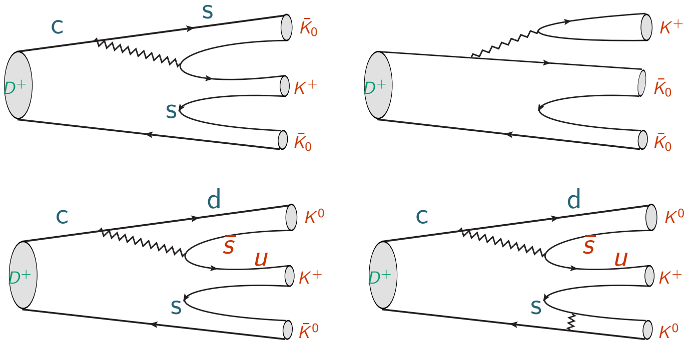
Amplitude Analysis

K^0 or $\bar{K}^0$?

A) K_S mesons decay from K^0 or $\bar{K}^0$?

- ✓ $D^+ \to K^+\bar{K}^0\bar{K}^0$ **CF**
- ✓ $D^+ \to K^+K^0\bar{K}^0$ **DCS, it's small**
- ✓ $D^+ \to K^+K^0K^0$ **It's very very very small**

B) So both are $\bar{K}^0$!!!



Resonance candidates

A) Resonance candidates

- ✓ $a_0(980)^+$, $a_2(1320)$, $\pi_1(1400)$, $a_0(1450)$, $\rho(1450)$, $\rho(1700)$
  No $a_2(1320)$, see: Shuai. Zhu, $D^+ \to K_S 3\pi$

B) Line Shape:

- ✓ **Flatte** : $a_0(980)^+$
- ✓ **GS** : ρ
- ✓ **RBW** : others

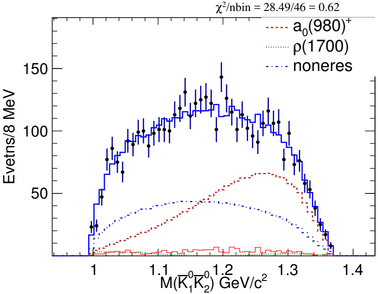
$Fix\ a_0(980)^+$

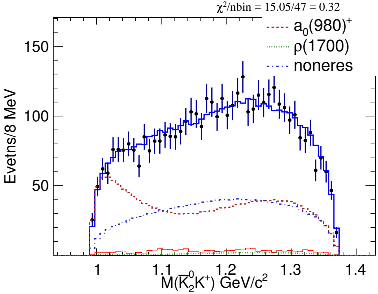
- ✓ Input: $\mathcal{B}(D^+ \to K_S\pi^+\eta)$, $\mathcal{B}(D^+ \to K^+ 2K_S)$, and $\frac{\Gamma(a_0 \to K\bar{K})}{\Gamma(a_0 \to \pi\eta)}$
- ✓ Expect: $FF(a_0^+) = 39.7 \pm 6.1\%$
- ✓ **Lagrange** multiplication factor

$$lnL = lnL_0 + \lambda \cdot |FF(a_0) - FF_{exp}| + g \cdot (FF(a_0) - FF_{exp})^2 \tag{7}$$

Preliminary result

✓ $a_0(980)^+ \; + \; \rho(1700) \; + \;$ none-res



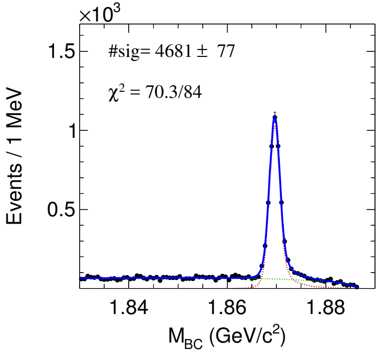


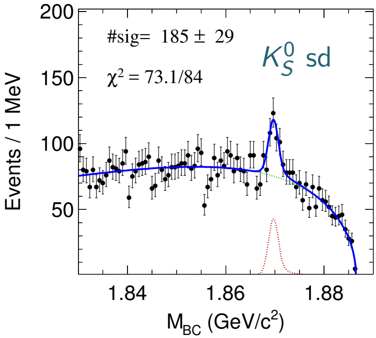
Preliminary result (2)

Fianl state	FF (%)	ϕ
$a_0^+ K_S$	39.7 (fixed)	0 (fixed)
$\rho(1700) K_S$	1.8	242 ± 14
none-resoance	35.8	220 ± 6

Determine $\mathcal{B}(D^+ \to K^+ 2K_S^0)$

- ✓ Without requirement Kinematic fit.
- ✓ Neglect the peak from **DCS** process $K^+4\pi$
- ✓ MCShape $\otimes$ **Gaus** + Argus





Branching fraction of $D^+ \to K^+ 2K_S^0$

Yield	peak background	n_{ST}	ϵ (%)
4681 ± 77	185 ± 29	4496 ± 83	19.38 ± 0.03

$$\mathcal{B} = \frac{n_{ST}}{\epsilon_{ST} \cdot 2N_{D^+D^-} \cdot \mathcal{B}(K_S^0 \to \pi^+\pi^-)} = (0.289 \pm 0.005)\% \tag{8}$$

✓ Consisted with **PDG** in 2σ

Uncertainty

source	uncertainty(%)
tracking	0.5 [1]
PID	0.5 [1]
K_S^0 reconstruction	3 [2]
cite BF	0.07
cite $N_{D^+D^-}$	0.9 [3]
requirement on ΔE	0.3
M_{BC} fit	0.4
model	0.4
sum	3.3

CP violation

✓ The A_{cp} is measured to be

$$A_{cp} = (2.8 \pm 2.6 \pm 1.1)\% \tag{9}$$

sample	Yield	peak background	Net
$D+$	2483 ± 57	93 ± 24	2390 ± 62
$D-$	2356 ± 55	97 ± 23	2259 ± 60

Summary

1. First measurement of $\mathcal{B}(D^+ \to \pi^+ K_S^0 \eta)$
2. Obtain the first amplitude result of $D^+ \to K^+ 2K_S^0$ and $\pi^+ K_S^0 \eta$
3. The $\mathcal{B}(D^+ \to K^+ 2K_S^0)$ Consisted with **PDG** in 2σ
4. The $A_{cp}(K^+ 2K_S^0)$ is measured to be

$$A_{cp} = (2.8 \pm 2.6 \pm 1.1)\% \tag{10}$$

Thanks !!!

References I

[1] J. Wei et al., *Measurements of Branching fractions of some PP decays of D^+ and D^0*, , http://docbes3.ihep.ac.cn/cgi-bin/DocDB/ShowDocument?docid=527.

[2] T. Ma, *Determination of K_S^0 effieicency systematics*, , http://docbes3.ihep.ac.cn/cgi-bin/DocDB/ShowDocument?docid=520.

[3] M. Ablikim et al., *Measurement of e+e- –¿ D Dbar Cross Sections at the psi(3770) Resonance*, , BESIII Collaboration, Chin. Phys. **C42** (2018) 083001, `arXiv:1803.06293 [hep-ex]`.