Dalitz Plot Analysis of D+ -> Ks pi^+ pi^0 @ BESIII

Chengdong Fu
Institute of High Energy Physics, Beijing
(for BESIII Collaboration)
The 6th International Workshop on Charm Physics
31 Aug – 4 Sep 2013, Manchester

List of Contents:
- Introduction
- BESIII Data
- Dalitz Technology
- Fit Results
- Summary
Introduction

- In D meson decay, there are many three bodies final states with large branching fraction and including $K\pi$ and $\pi\pi$ two body resonances.
- $K\pi$ is a special and interesting system
  - $K\pi$ S wave
  - numerous $K$ excited states: $K^*(892), K_0^*(1430), K^*(1680)$, etc.
- $K\pi$ S wave and low-mass $K\pi$ scalar resonance $\kappa(800)$ have been observed significantly in earlier experiments (MARKIII, NA14, E691-791, CLEO) through dalitz plot analysis.
- The $D^+\rightarrow K_S\pi^+\pi^0$ decay as one of gold channels, is needed to obtain more precision structure.

BES has established the Dalitz plot analysis, this analysis is one of the Dalitz plot analysis @BESIII.

CD. Fu, DPA of D->Kpipi0@Charm2013

2013/8/26
BESIII Detector and Data

Magnet: 1 T Superconducting

EMCAL: CsI crystal
\[ \Delta E/E = 2.5\% @ 1\text{ GeV} \]
\[ \sigma_{\phi,z} = 0.5-0.7 \text{ cm}/\sqrt{E} \]

Data Acquisition:
Event rate = 3 kHz
Throughput \sim 50 \text{ MB/s}

MDC: small cell & He gas
\[ \sigma_{xy} = 130 \text{ \mu m} \]
\[ s_{p/p} = 0.5\% @ 1\text{ GeV} \]
\[ dE/dx = 6\% \]

TOF:
\[ \sigma_T = 90\text{ ps Barrel} \]
\[ 110\text{ ps Endcap} \]

Muon ID: 8-9 layer RPC
\[ \sigma_{R\phi} = 1.4 \text{ cm} \sim 1.7 \text{ cm} \]

Trigger: Tracks & Showers
Pipelined; Latency = 6.4 \mu s

Total about \textbf{2.9/}fb \( \psi(3770) \) data are taken at BESIII, in 2010 and 2011

CD. Fu, DPA of D->Kpipi0@Charm2013
Signal and Sideband

- ~167k events are selected in signal region.
- Shape of Argus background on Dalitz plot is estimated by combination of two sidebands (left & right).
- A peaking background is very small (~0.6% of signal) is estimated by MC shape:
  - $\pi^+(K_s) \leftrightarrow \pi^+(D)$

### A RooFit Figure

**Signal region:** 84.9% SIG + 15.1% BG

![Graph showing signal and sideband](image)

**MC shape**
Maximum Likelihood Fit

- The log-likelihood function is defined as:
  \[ \ln L = \sum_{i=1}^{N} \ln \mathcal{P}(x_i, y_i) \]

- p.d.f. is:
  \[ \mathcal{P}(x, y) = \begin{cases} 
  \frac{\varepsilon(x,y)}{\int_{D_P} \varepsilon(x,y) dx dy} & 
  \frac{\varepsilon(x,y) M(x,y)^2}{\int_{D_P} \varepsilon(x,y) M(x,y)^2 dx dy} \\
  \frac{B_1(x,y)}{\int_{D_P} B_1(x,y) dx dy} & 
  \frac{f_S \int_{D_P} |M(x,y)|^2 \varepsilon(x,y) dx dy + f_{B1} \int_{D_P} B_1(x,y) dx dy + f_{B2} \int_{D_P} B_2(x,y) dx dy}{\int_{D_P} |M(x,y)|^2 \varepsilon(x,y) dx dy} 
\end{cases} \]

- For efficiency: 3rd polynomial function \( \otimes \) threshold factor
  - PHSP generator
  - DALITZ generator

- For Argus BG: resonances \( \rho^+, K^0, K^+ \)

- For signal with background, the efficiency and the backgrounds are fixed as parameterized shapes:
  \[ f_S + f_{B1} + f_{B2} = 1 \]
Isobar Model and Fit Fraction

- Decay matrix element
  \[ M = \sum_{L=0}^{L_{\text{max}}} Z_L F_D^L A_L \]
- \( A_L = \sum_R W_R^L = \sum_R c_R W_R^L F_R^L \)
- \( c_R \) is complex parameter to fit
- \( W_R \) is dynamical function, generally, a Breit-Wigner function.
  \[ W_R(m_{ab}) = \frac{1}{m_R^2 - m_{ab}^2 - i m_R \Gamma(m_{ab})} \]
- For special resonance, such as \( \kappa(800) \)
  \[ W_R(m_{ab}) = \frac{1}{s_R - m_{ab}^2} \]
- For any intermediate resonance, its fraction is calculated by
  \[ FF_i = \frac{\int |A_i(x, y)|^2 dxdy}{\int |M(x, y)|^2 dxdy} \]
- For combined fraction,
  \[ FF_C = \frac{\int \sum_C |A_k(x, y)|^2 dxdy}{\int |M(x, y)|^2 dxdy} \]

K\pi S wave is a sum of \( \kappa(800) \), K*0bar(1430) and non-resonant.
In order to approximate background shape, two sidebands are used to parameterize background.

In the right sideband, there are obvious signal components, because of ISR.

Parameterized by background + signal

Signal is initialized by left sideband

Iterate to approach the real amplitude of signal more and more

Left: (a)(b)(c); right: (d)(e)(f); combined: (g)(h)(i)
Fit to Data using Isobar Model

- Model with K*bar and ρ cannot describe our data well, more intermediate resonances are considered.
- Float parameters of K*0bar(1430) and κ(800)

<table>
<thead>
<tr>
<th>Cabbibo flavor</th>
<th>Doubly Cabbibo suppress</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_S^+X^+$</td>
<td>$X^+\pi^+$</td>
</tr>
<tr>
<td>$K_S^0\rho(770)^+$</td>
<td>$\bar{K}^+(892)^0\pi^+$</td>
</tr>
<tr>
<td>$K_S^0\rho(1450)^+$</td>
<td>$\bar{K}_0^+(1430)^0\pi^+$</td>
</tr>
<tr>
<td>$\bar{K}^+(1680)^0\pi^+$</td>
<td>$\bar{K}^+(1680)^0\pi^+$</td>
</tr>
<tr>
<td>$\pi(800)^0\pi^+$</td>
<td>$\pi(800)^0\pi^+$</td>
</tr>
<tr>
<td>$K_S^0\rho(1700)^+$</td>
<td>$K^+(1410)^0\pi^+$</td>
</tr>
<tr>
<td>$\bar{K}_2^+(1430)^0\pi^+$</td>
<td>$\bar{K}_2^+(1430)^0\pi^+$</td>
</tr>
<tr>
<td>$\bar{K}_3^+(1780)^0\pi^+$</td>
<td>$\bar{K}_3^+(1780)^0\pi^+$</td>
</tr>
</tbody>
</table>

No evidences for DCS channels
Momentum-dependent Correction for Efficiency

- The differences of efficiency between MC and data are momentum dependent, for $K_s/\pi^0$ reconstruction and $\pi$ tracking/PID.
- At different position on Dalitz plot, the distributions of momentum are different.
- These two cause that efficiency correcting factor should be different at different position $(x,y)$. Therefore, a momentum-dependent correction is perform.

A MC study for efficiency correction:
black for real, red for uncorrected, blue (matched with black) for corrected.
Corrected Results and Errors

- Resolution and integration are estimated to be ignored.
- For modeling errors
  - Shape: angle distribution, form factor and resonance shape
  - Add: additional resonances

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Stat</th>
<th>Experimental Errors</th>
<th>Modeling Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR FF(%)</td>
<td>4.63</td>
<td>0.67</td>
<td>3.45 0.96 3.59</td>
<td>+2.89 +2.65 +3.97</td>
</tr>
<tr>
<td>NR Phase</td>
<td>278.62</td>
<td>5.36</td>
<td>4.32 14.27 14.91</td>
<td>-1.50 -3.24 -3.57</td>
</tr>
<tr>
<td>(\rho(770)^+) FF(%)</td>
<td>83.41</td>
<td>2.19</td>
<td>2.66 0.62 2.74</td>
<td>+5.96 +21.61 +22.42</td>
</tr>
<tr>
<td>(\rho(1450)^+) FF(%)</td>
<td>2.13</td>
<td>0.22</td>
<td>0.87 0.82 1.20</td>
<td>-24.40 -11.54 -26.99</td>
</tr>
<tr>
<td>(\rho(1450)^+) Phase</td>
<td>187.02</td>
<td>2.56</td>
<td>3.03 3.69 4.78</td>
<td>-1.87 -1.05 -2.15</td>
</tr>
<tr>
<td>(K^*(892)^0) FF(%)</td>
<td>3.58</td>
<td>0.17</td>
<td>0.12 0.11 0.11</td>
<td>+1.02 +6.33 +6.42</td>
</tr>
<tr>
<td>(K^*(892)^0) Phase</td>
<td>293.22</td>
<td>1.25</td>
<td>0.73 1.45 1.63</td>
<td>+1.82 +1.48 +1.48</td>
</tr>
<tr>
<td>(K_0^*(1430)^0) FF(%)</td>
<td>3.66</td>
<td>0.57</td>
<td>0.50 0.42 0.71</td>
<td>-3.53 -4.63 -15.25</td>
</tr>
<tr>
<td>(K_0^*(1430)^0) Phase</td>
<td>334.36</td>
<td>4.73</td>
<td>4.38 3.63 8.23</td>
<td>+0.31 +0.16 +0.35</td>
</tr>
<tr>
<td>(K^*(1680)^0) FF(%)</td>
<td>1.27</td>
<td>0.11</td>
<td>0.60 0.16 0.63</td>
<td>-0.18 -0.28 -0.34</td>
</tr>
<tr>
<td>(K^*(1680)^0) Phase</td>
<td>251.82</td>
<td>1.90</td>
<td>8.45 5.60 10.14</td>
<td>+1.12 +5.67 +5.78</td>
</tr>
<tr>
<td>(\kappa^0) FF(%)</td>
<td>7.73</td>
<td>1.19</td>
<td>2.43 3.09 3.94</td>
<td>-6.52 -1.17 -6.63</td>
</tr>
<tr>
<td>(\kappa^0) Phase</td>
<td>92.89</td>
<td>6.23</td>
<td>24.24 13.55 27.77</td>
<td>+0.34 +0.66 +0.75</td>
</tr>
<tr>
<td>NR + (\kappa^0) FF(%)</td>
<td>18.59</td>
<td>1.69</td>
<td>1.08 0.95 1.44</td>
<td>-0.29 -0.74 -0.80</td>
</tr>
<tr>
<td>(K^0) S wave</td>
<td>17.29</td>
<td>1.34</td>
<td>2.01 0.49 2.07</td>
<td>+0.33 +2.04 +2.07</td>
</tr>
</tbody>
</table>

CD. Fu, DPA of D->Kpipi0@Charm2013

BESIII Preliminary
The size of sample is close to CLEO-c's $D^+ \rightarrow K^- \pi^+ \pi^+$, and $D^+ \rightarrow Ks\pi^+\pi^0$ is a complementary channel for some intermediate channels, such as $K^*\overline{b}(892)\pi$, $K^*\overline{0}(1430)\pi$, etc.

$$r = \frac{Br(Ks\pi\pi0)}{Br(K\pi\pi)} \times 2 \times 2$$

PDG2012: $3.06 \pm 0.14$

<table>
<thead>
<tr>
<th>Mode</th>
<th>BESIII</th>
<th>CLEO-c</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^*\overline{b}(892)\pi^+$</td>
<td>3.58 ± 0.17</td>
<td>11.2 ± 0.2</td>
<td>3.13 ± 0.16</td>
</tr>
<tr>
<td>$K^*\overline{0}(1430)\pi^+$</td>
<td>3.7 ± 0.6</td>
<td>10.4 ± 0.6</td>
<td>2.8 ± 0.5</td>
</tr>
</tbody>
</table>

The results are consistent with CLEO-c.
The mass and width of $K^*(1430)$ are consistent with E791 and CLEO-c from $D^+ \rightarrow K^- \pi^+ \pi^+$. Another fit to model without $\kappa(800)$ gives $m(K^*(1430)) = 1444 \pm 4$ MeV, $\Gamma(K^*(1430)) = 283 \pm 11$ MeV, consistent with the value of PDG2012. The pole of $\kappa(800)$ is consistent with the model C of CLEO-c.
Cross-check with Model-Independent PWA

For some interested resonances, a binned amplitude is used. Other resonances are kept same as isobar model.

\[ \mathcal{W}_{L, \text{binned}}(s) = a_L(s) e^{i\phi_L(s)} \]

First by E791

PRD 73, 032004 (2006)

The K*0bar(1430) is destructive interfered with \( \kappa(800) \) and non-resonant, which can explain the fraction of \( K\pi \) S wave smaller than the combine of \( \kappa(800) \) and non-resonant.

The phase shift can be described by NR+\( \kappa(800) \) well.
Based on Dalitz analysis technology at BESIII, a Dalitz analysis of the $D^+ \to K_S \pi^+ \pi^0$ decay is performed using $\sim 167k$ events with a background of about 15% at BESIII. We fit distribution of data to a coherent sum of six intermediate resonances (including a low mass scalar resonance $\kappa$) plus a non-resonant component.

The fit fractions multiplied by the world average $D^+ \to K_S \pi^+ \pi^0$ branching ratio of $(6.99 \pm 0.27)\%$, yield the partial branching fractions, which is consistent with E791 and CLEO-c at the $D^+ \to K_S \pi^+ \pi^0$ decay.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Partial Branching Fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B(D^+ \to K_S^0 \pi^+ \pi^0)$ Non Resonant</td>
<td>0.32±0.05±0.25±0.21</td>
</tr>
<tr>
<td>$B(D^+ \to \rho^+ K_S^0) \times B(\rho \to \pi^+ \pi^0)$</td>
<td>5.83±0.16±0.30±0.63</td>
</tr>
<tr>
<td>$B(D^+ \to \rho(1450)^+(K_S^0) \times B(\rho(1450)^+ \to \pi^+ \pi^0)$</td>
<td>0.15±0.02±0.09±0.13</td>
</tr>
<tr>
<td>$B(D^+ \to K^+(892)^0 \pi^+) \times B(K^+(892)^0 \to K_S^0 \pi^0)$</td>
<td>0.250±0.012±0.015±0.022</td>
</tr>
<tr>
<td>$B(D^+ \to K_0^+(1430)^0 \pi^+) \times B(K_0^+(1430)^0 \to K_S^0 \pi^0)$</td>
<td>0.26±0.04±0.05±0.03</td>
</tr>
<tr>
<td>$B(D \to K^+(1680)^0 \pi^+) \times B(K^+(1680)^0 \to K_S^0 \pi^0)$</td>
<td>0.09±0.01±0.05±0.08</td>
</tr>
<tr>
<td>$B(D^+ \to \kappa^0 \pi^+) \times B(\kappa^0 \to K_S^0 \pi^0)$</td>
<td>0.54±0.09±0.28±0.19</td>
</tr>
<tr>
<td>$\text{NR} \to K_S^0 \pi^+$</td>
<td>1.30±0.12±0.12±0.30</td>
</tr>
<tr>
<td>$K_S^0 \pi^0$ S wave</td>
<td>1.21±0.10±0.16±0.27</td>
</tr>
</tbody>
</table>

PDG 2012:  
0.9 ±0.7  
4.7±1.0  
1.3±0.6
Thank you for your attention!