Dalitz Plot Analysis of D+→Ks π⁺ π₀@BESIII

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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 is a complementary channel to study $K\pi$ wave.

BES has established the Dalitz plot analysis, this analysis is one of the Dalitz plot analysis @BESIII.
**BESIII Detector and Data**

BESIII detector is working on the e⁺e⁻ collision BEPCII, designed peak luminosity $\sim 10^{33}\text{cm}^{-1}\text{s}^{-1}$.

**TOF**: $\sigma_T = 90\text{ps}$ barrel, $110\text{ps}$ endcap

**MDC**: $\sigma_{xy} = 130\mu\text{m}$, $\delta_p / p = 0.5\%$ @1GeV, $dE/dx \ 6\%$

**CsI(Tl) EMC**: $\Delta E/E = 2.5\%$ @1GeV, $\sigma_{r\phi,z} = 0.5\sim0.7\text{cm}$ @1GeV

**RPC MUON**: $\sigma_{r\phi,z} = 1.4\sim1.7\text{cm}$

**Total about 2.9/fb $\psi(3770)$ data are taken at BESIII, in 2010 and 2011**
Signal and Sideband

- ~167k events are selected in signal region.
  - MC shape (with a Gaussian resolution) + Argus
- 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), estimated by MC shape: 
  - $\pi^+(K_s) \leftrightarrow \pi^+(D)$

A RooFit Figure

<table>
<thead>
<tr>
<th>Events / 0.9MeV</th>
<th>20000</th>
<th>18000</th>
<th>16000</th>
<th>14000</th>
<th>12000</th>
<th>10000</th>
<th>8000</th>
<th>6000</th>
</tr>
</thead>
<tbody>
<tr>
<td>m_{rec} (GeV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Events / 0.9MeV</td>
<td>2000</td>
<td>4000</td>
<td>6000</td>
<td>8000</td>
<td>10000</td>
<td>12000</td>
<td>14000</td>
<td>16000</td>
</tr>
<tr>
<td>m_{rec} (GeV)</td>
<td>1.82</td>
<td>1.83</td>
<td>1.84</td>
<td>1.85</td>
<td>1.86</td>
<td>1.87</td>
<td>1.88</td>
<td>1.89</td>
</tr>
</tbody>
</table>

Signal region: 84.9% SIG + 15.1% BG

Sideband

MC shape
Maximum Likelihood Fit

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

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

- For efficiency: 3\textsuperscript{rd} polynomial function $\otimes$ threshold factor
  - PHSP generator or DALITZ generator
    - PHSP generator
    - DALITZ generator
  - No obvious difference is found.

- For Argus BG: resonances $\rho^+, K^0, K^{*+}$

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

- Decay matrix element
  \[ M = \sum_{L=0}^{L_{max}} Z_L F_D^L A_L \]
  \[ A_L = \sum_R W_R^L = \sum_R c_R W_R^L F_R^L \]

- \( c_R \) 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
  \( F F_i = \frac{\int |A_i(x, y)|^2 dxdy}{\int |M(x, y)|^2 dxdy} \)
  \( F F_C = \frac{\int |\sum_C A_k(x, y)|^2 dxdy}{\int |M(x, y)|^2 dxdy} \)

K\( \pi \) S wave is a sum of \( \kappa(800), K^*0\text{bar}(1430) \) and non-resonant.
Shape Approximation for Argus BG

- 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)

Signal component
Model with $K^*\bar{\rho}$ and $\rho$ cannot describe our data well, more intermediate resonances are considered.

Float parameters of $K^*\rho(1430)$ and $\kappa(800)$

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Favor</th>
<th>w/o NR $\kappa$</th>
<th>Final Res.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-resonant</td>
<td>4.5±0.7</td>
<td>269±6</td>
<td>232.7±1.3</td>
</tr>
<tr>
<td>$K^0_S\rho(770)^+$</td>
<td>84.6±1.8</td>
<td>0.6±0.0</td>
<td>82.0±1.3</td>
</tr>
<tr>
<td>$K^0_S\rho(1450)^+$</td>
<td>1.80±0.20</td>
<td>138±4</td>
<td>6.03±0.29</td>
</tr>
<tr>
<td>$K^+(892)^0\pi^+$</td>
<td>3.22±0.11</td>
<td>204.7±1.3</td>
<td>2.99±0.10</td>
</tr>
<tr>
<td>$K^+(1410)^0\pi^+$</td>
<td>0.12±0.05</td>
<td>228±9</td>
<td>0.18±0.05</td>
</tr>
<tr>
<td>$K^+(1430)^0\pi^+$</td>
<td>1.5±0.6</td>
<td>319±5</td>
<td>10.5±1.3</td>
</tr>
<tr>
<td>$K_0^+(1450)^0\pi^+$</td>
<td>1.118±0.018</td>
<td>273±7</td>
<td>0.086±0.014</td>
</tr>
<tr>
<td>$K^+(1680)^0\pi^+$</td>
<td>0.21±0.06</td>
<td>243±6</td>
<td>0.58±0.08</td>
</tr>
<tr>
<td>$K_0^+(1780)^0\pi^+$</td>
<td>0.034±0.008</td>
<td>130±12</td>
<td>0.055±0.008</td>
</tr>
<tr>
<td>$\kappa(0)^0\pi^+$</td>
<td>6.8±0.7</td>
<td>92±6</td>
<td>18.8±0.5</td>
</tr>
</tbody>
</table>

No evidences for DCS channels
Momentum-dependent Correction for Efficiency

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

A MC study for efficiency correction:
- **black** for real, **red** for uncorrected, **blue** (matched well 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 Image]
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 $K^*\bar{b}ar(892)\pi$, $K^*0\bar{b}ar(1430)\pi$, etc.

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

PDG2012: 3.06±0.14

The results are consistent with CLEO-c.

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

Statistical error only
The mass and width of K*0(1430) are consistent with E791 and CLEO-c from D^+→K^-π^+π^+.

Another fit to model without κ(800) gives m(K*0(1430))=1444±4 MeV, Γ(K*0(1430))=283±11 MeV, consistent with the value of PDG2012, but it has poorer goodness than model with κ(800).

The pole of κ(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.

- First by E791 at $D^+ \rightarrow K^-\pi^+\pi^+$.

- The $K^*0\bar{\text{bar}}(1430)$ 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.
Summary and Conclusion

Based on Dalitz analysis technology at BESIII, a Dalitz analysis of the \( D^+ \to K_S \pi^+ \pi^0 \) decay is performed using \(~167k\) 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 \( D^+ \to K^- \pi^+ \pi^+ \) 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 \pm 0.05 \pm 0.25 )</td>
</tr>
<tr>
<td>( B(D^+ \to \rho^+ K_S^0) \times B(\rho^- \to \pi^+ \pi^0) )</td>
<td>( 5.83 \pm 0.16 \pm 0.08 )</td>
</tr>
<tr>
<td>( B(D^+ \to \rho(1450)^+ K_S^0) \times B(\rho(1450)^- \to \pi^+ \pi^0) )</td>
<td>( 0.15 \pm 0.02 \pm 0.09 )</td>
</tr>
<tr>
<td>( B(D^+ \to K_S^*(892)^0 \pi^+) \times B(K_S^- \to K_S^- \pi^0) )</td>
<td>( 0.250 \pm 0.012 \pm 0.015 )</td>
</tr>
<tr>
<td>( B(D^+ \to K_S^*(1430)^0 \pi^+) \times B(K_S^0 \to K_S^0 \pi^0) )</td>
<td>( 0.26 \pm 0.04 \pm 0.06 )</td>
</tr>
<tr>
<td>( B(D^+ \to K_S^*(1680)^0 \pi^+) \times B(K_S^0 \to K_S^- \pi^0) )</td>
<td>( 0.09 \pm 0.01 \pm 0.04 )</td>
</tr>
<tr>
<td>( B(D^+ \to K_S^0 \pi^0 \pi^+) \times B(K^0 \to K_S^0 \pi^0) )</td>
<td>( 0.54 \pm 0.09 \pm 0.14 )</td>
</tr>
<tr>
<td>NR+( \kappa^0 \pi^+ )</td>
<td>( 1.30 \pm 0.12 \pm 0.30 )</td>
</tr>
<tr>
<td>( K_S^0 \pi^0 ) S wave</td>
<td>( 1.21 \pm 0.10 \pm 0.27 )</td>
</tr>
</tbody>
</table>

\( \frac{Br(D^+ \to K_S^0 \pi^+ \pi^- \rightarrow K^- \pi^+ \pi^+)}{Br(D^+ \to K_S^0 \pi^+ \pi^0 \rightarrow K^0 \pi^+ \pi^0)} = 2.02 \pm 0.34 \)
Thank you for your attention!