Dalitz Plot Analysis of D+->Ks pi+ pi0@BESIII

SUN Shengsen

Institute of High Energy Physics, Beijing

(for BESIII Collaboration)

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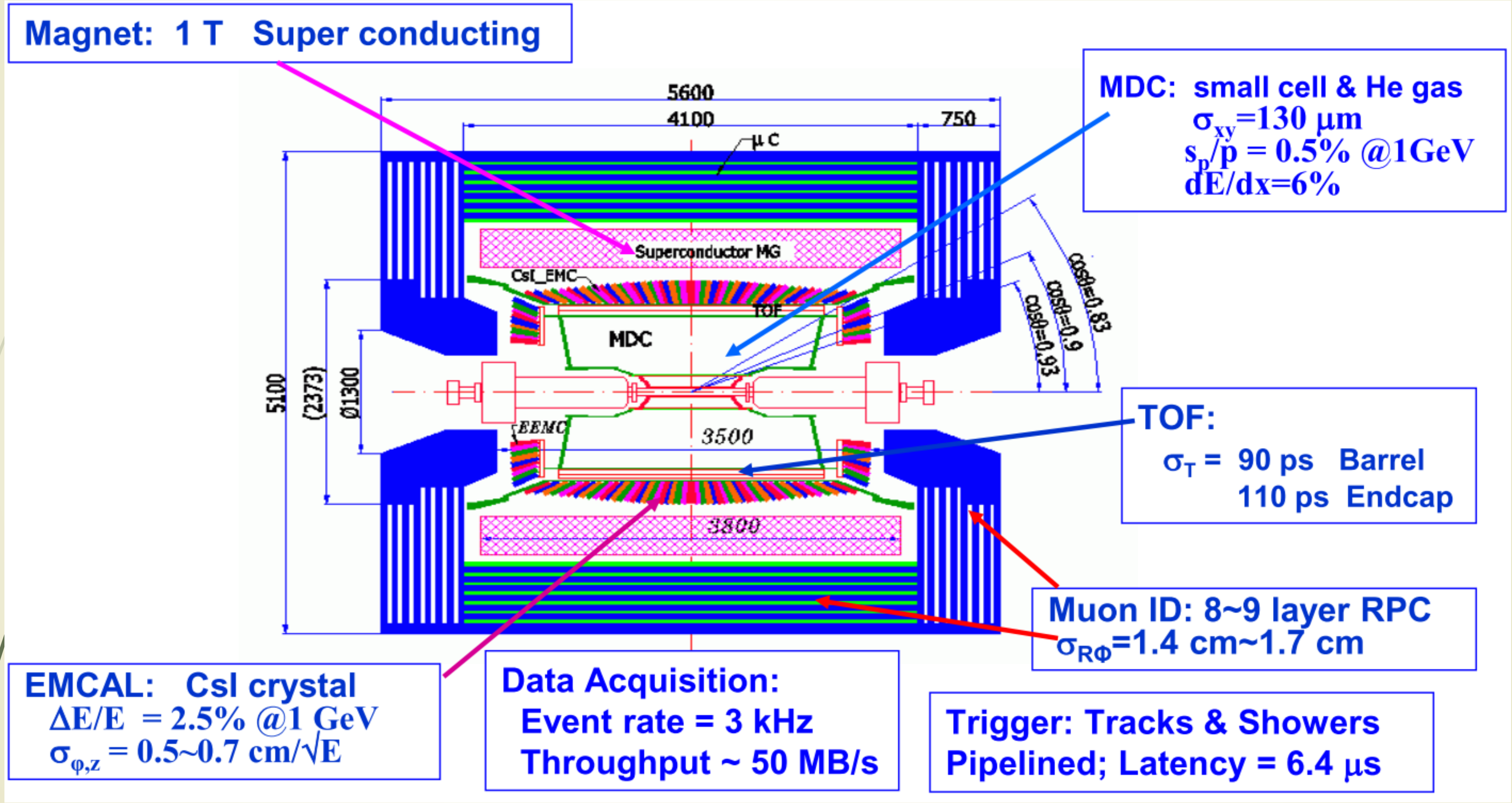
Introduction

- 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 κ(800) have been observed significantly in earlier experiments (MARKIII, NA14, E691-791, CLEO) through dalitz plot analysis.
- The $D^+ \to K_S \pi^+ \pi^0$ 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.

NIM A614, 345(2010)

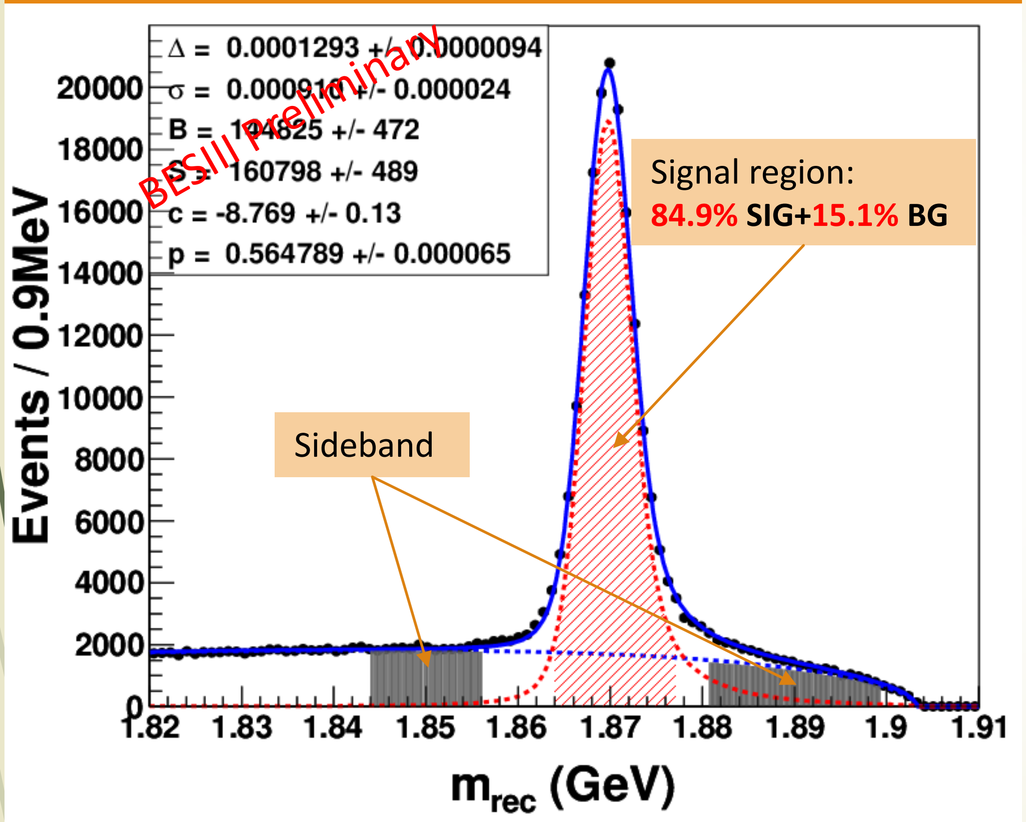
BESIII Detector and Data



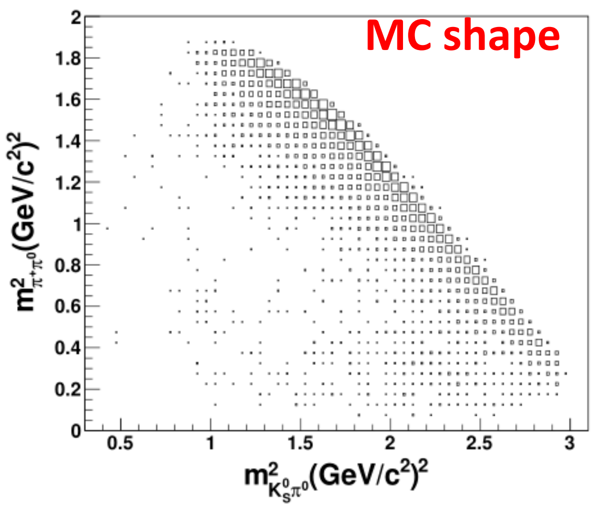
Total about **2.9/fb** ψ(3770) data are taken at BESIII, in 2010 and 2011

Signal and Sideband

A RooFit Figure



- ~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:
  - $\pi^+(Ks)\leftrightarrow\pi^+(D)$



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

$$\mathcal{P}(x,y) = \begin{cases} \frac{\varepsilon(x,y)}{\int_{DP} \varepsilon(x,y)dxdy} \\ \frac{\varepsilon(x,y)|\mathcal{M}(x,y)|^2}{\int_{DP} \varepsilon(x,y)|\mathcal{M}(x,y)|^2 dxdy} \\ \frac{B_1(x,y)}{\int_{DP} B_1(x,y)dxdy} \\ f_S \frac{|\mathcal{M}(x,y)|^2 \varepsilon(x,y)}{\int_{DP} |\mathcal{M}(x,y)|^2 \varepsilon(x,y)dxdy} + f_{B1} \frac{B_1(x,y)}{\int_{DP} B_1(x,y)dxdy} + f_{B2} \frac{B_2(x,y)}{\int_{DP} B_2(x,y)dxdy} \end{cases}$$

for efficiency by PHSP

for efficiency by DALITZ

for Argus BG

for signal with BG

Histogram p.d.f. from MC

- For efficiency: 3rd polynomial function ⊗ threshold factor

PHSP generator or DALITZ generator

No obvious difference is found.

- For Argus BG: resonances ρ^+, 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

$$\mathcal{M} = \sum_{L=0}^{L_{max}} Z_L F_D^L A_L$$

Angle distribution

Form factor

$$A_L = \sum_R \mathcal{W}_R^L = \sum_R c_R W_R^L F_R^L$$

- 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 κ(800)

$$W_R(m_{ab}) = \frac{1}{s_R - m_{ab}^2}$$

- For any intermediate resonance, its fraction is calculated by

$c_R Z_L F_D^L F_R^L W_R$

$$FF_i = \frac{\int |\mathcal{A}_i(x,y)|^2 dxdy}{\int |\mathcal{M}(x,y)|^2 dxdy}$$

  - For combined fraction,

$$FF_C = \frac{\int |\sum_C \mathcal{A}_k(x,y)|^2 dxdy}{\int |\mathcal{M}(x,y)|^2 dxdy}$$

Kπ S wave is a sum of κ(800), K*0bar(1430) and non-resonant.

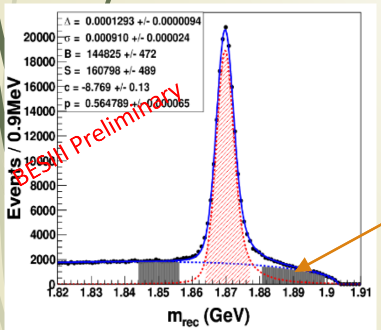
Shape Approximation for Argus BG

- 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

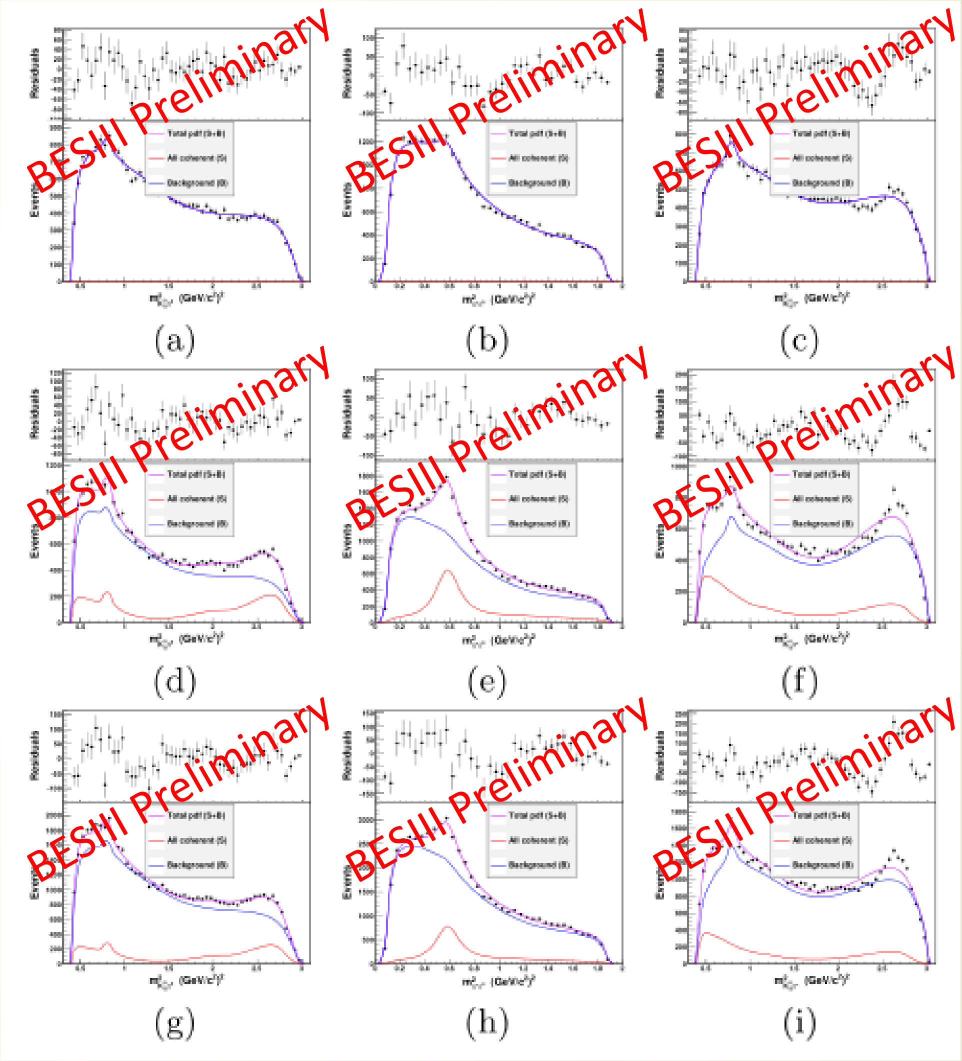
Left: (a)(b)(c);

right: (d)(e)(f);

combined: (g)(h)(i)



Signal component



Fit to Data using Isobar Model

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- 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)

Cabbibo flavor		Doubly Cabbibo suppress
$K_S^0 X^+$	$X^0 \pi^+$	$X^+ \pi^0$
$K_S^0 \rho(770)^+$ $K_S^0 \rho(1450)^+$	$\overline{K}^*(892)^0 \pi^+$ $\overline{K}_0^*(1430)^0 \pi^+$ $\overline{K}^*(1680)^0 \pi^+$ $\overline{\kappa}(800)^0 \pi^+$	$\overline{K}^*(892)^+ \pi^0$ $\overline{K}_0^*(1430)^+ \pi^0$ $\overline{K}^*(1680)^+ \pi^0$ $\overline{\kappa}(800)^+ \pi^0$
$K_S^0 \rho(1700)^+$	$\overline{K}^*(1410)^0 \pi^+$ $\overline{K}_2^*(1430)^0 \pi^+$ $\overline{K}_3^*(1780)^0 \pi^+$	$\overline{K}^*(1410)^+ \pi^0$ $\overline{K}_2^*(1430)^+ \pi^0$ $\overline{K}_3^*(1780)^+ \pi^0$

No evidences for DCS channels

Decay Mode	Favor		w/o κ		w/o NR		Final Res.	
	FF(%)	Phase	FF(%)	Phase	FF(%)	Phase	FF(%)	Phase
Non-resonant	4.5±0.7	269±6	18.3±0.6	232.7±1.3			6.1±0.9	276±6
$K_S^0 \rho(770)^+$	84.6±1.8	0(fixed)	82.0±1.3	0(fixed)	86.7±1.1	0(fixed)	82.2±2.2	0(fixed)
$K_S^0 \rho(1450)^+$	1.80±0.20	198±4	6.03±0.29	167.1±2.1	0.63±0.12	186±8	2.65±0.28	183.7±2.6
$\overline{K}^*(892)^0 \pi^+$	3.22±0.14	294.7±1.3	2.99±0.10	279.3±1.2	3.30±0.10	292.3±1.5	3.38±0.16	292.2±1.3
$\overline{K}^*(1410)^0 \pi^+$	0.12±0.05	228±9	0.18±0.05	301±10	0.12±0.05	243±12		
$\overline{K}_0^*(1430)^0 \pi^+$	4.5±0.6	319±5	10.5±1.3	306.2±2.0	3.6±0.5	317±4	3.7±0.6	339±5
$\overline{K}_2^*(1430)^0 \pi^+$	0.118±0.018	273±7	0.086±0.014	265±9	0.111±0.015	267±7		
$\overline{K}^*(1680)^0 \pi^+$	0.21±0.06	243±6	0.58±0.08	284±4	0.43±0.10	234±5	1.05±0.09	255.3±2.0
$\overline{K}_3^*(1780)^0 \pi^+$	0.034±0.008	130±12	0.055±0.008	113±9	0.037±0.008	131±11		
$\kappa^0 \pi^+$	6.8±0.7	92±6			18.8±0.5	11.6±1.9	6.4±1.0	92±7
$K_S^0 \pi^0$ S wave w/o $\overline{K}_0(1430)$	18.1±1.4		18.3±0.6		18.8±0.5		19.2±1.8	
ΣFF(%)	106		121		114		105	
χ^2/n	1672/1209		2497/1209		1777/1209		2068/1209	
$\mathcal{L}$	239415		240284		239521		239807	

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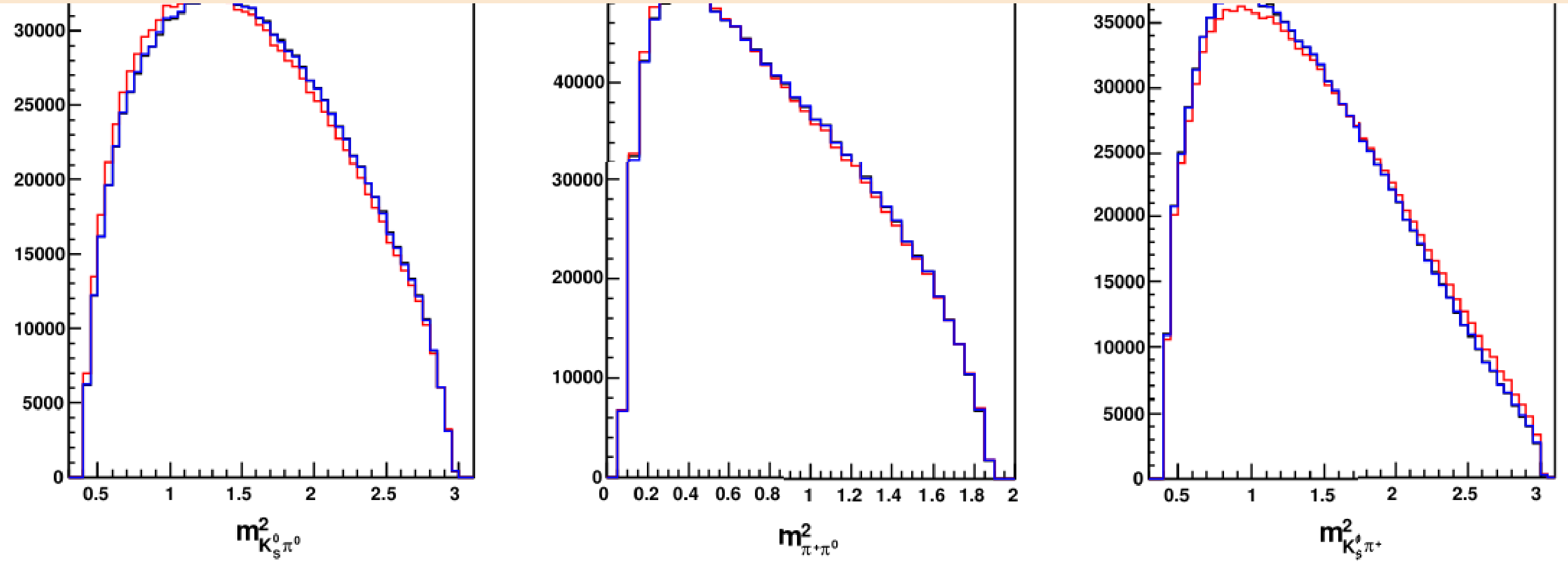
Momentum-dependent Correction for Efficiency

- The differences of efficiency between MC and data are momentum dependent, for Ks/π0 reconstruction and π 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.

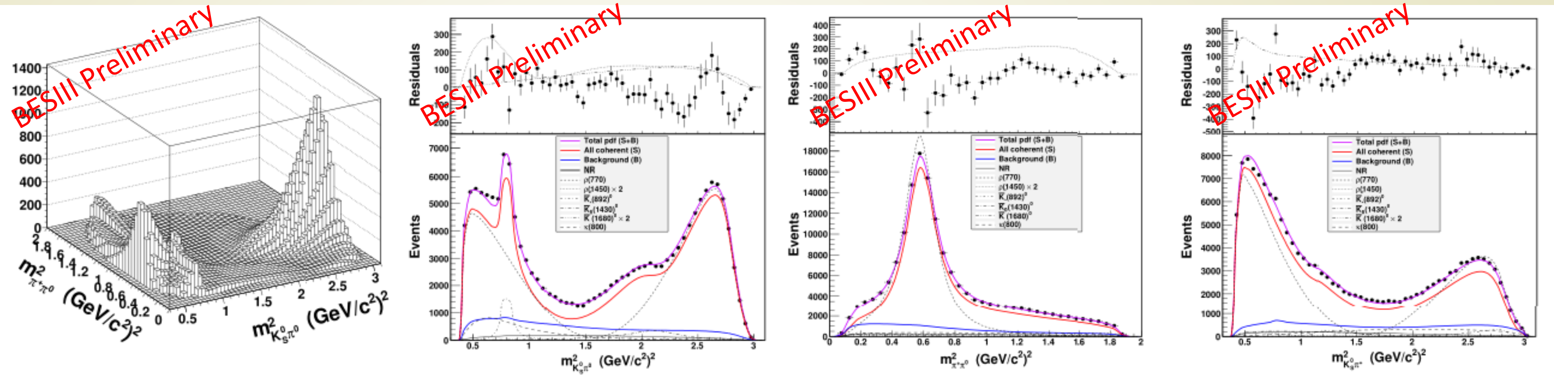


Corrected Results and Errors

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

Parameters	Value	Stat	Experimental Errors			Modeling Errors		
			Bkg	Eff	Total	Shape	Add	Total
NR FF(%)	4.63	0.67	3.45	0.96	3.59	$^{+2.89}_{-1.50}$	$^{+2.65}_{-3.24}$	$^{+3.93}_{-3.57}$
NR Phase	278.62	5.36	4.32	14.27	14.91	$^{+5.96}_{-24.40}$	$^{+21.61}_{-11.54}$	$^{+22.42}_{-26.99}$
$\rho(770)^+$ FF(%)	83.41	2.19	2.66	0.62	2.74	$^{+1.02}_{-1.87}$	$^{+6.33}_{-1.05}$	$^{+6.42}_{-2.15}$
$\rho(1450)^+$ FF(%)	2.13	0.22	0.87	0.82	1.20	$^{+0.62}_{-0.02}$	$^{+0.73}_{-1.48}$	$^{+0.96}_{-1.48}$
$\rho(1450)^+$ Phase	187.02	2.56	3.03	3.69	4.78	$^{+5.66}_{-14.53}$	$^{+25.67}_{-4.63}$	$^{+27.09}_{-15.25}$
$\overline{K}^*(892)^0$ FF(%)	3.58	0.17	0.12	0.11	0.17	$^{+0.31}_{-0.18}$	$^{+0.16}_{-0.28}$	$^{+0.35}_{-0.34}$
$\overline{K}^*(892)^0$ Phase	293.22	1.25	0.73	1.45	1.63	$^{+1.12}_{-6.52}$	$^{+5.67}_{-1.17}$	$^{+5.78}_{-6.63}$
$\overline{K}^*_0(1430)^0$ FF(%)	3.66	0.57	0.57	0.42	0.71	$^{+0.34}_{-0.29}$	$^{+0.66}_{-0.74}$	$^{+0.75}_{-0.80}$
$\overline{K}^*_0(1430)^0$ Phase	334.36	4.73	7.38	3.63	8.23	$^{+0.33}_{-9.53}$	$^{+2.04}_{-27.43}$	$^{+2.07}_{-29.04}$
$\overline{K}^*(1680)^0$ FF(%)	1.27	0.11	0.60	0.16	0.63	$^{+0.51}_{-0.07}$	$^{+0.01}_{-1.07}$	$^{+0.52}_{-1.08}$
$\overline{K}^*(1680)^0$ Phase	251.81	1.90	8.45	5.60	10.14	$^{+5.70}_{-1.21}$	$^{+6.92}_{-27.87}$	$^{+8.97}_{-27.90}$
κ^0 FF(%)	7.73	1.19	2.43	3.09	3.94	$^{+1.93}_{-2.64}$	$^{+4.70}_{-0.10}$	$^{+5.09}_{-2.65}$
κ^0 Phase	92.89	6.23	24.24	13.55	27.77	$^{+13.17}_{-6.56}$	$^{+15.72}_{-21.52}$	$^{+20.51}_{-22.50}$
NR+κ^0 FF(%)	18.59	1.69	1.08	0.95	1.44	$^{+1.54}_{-3.70}$	$^{+0.50}_{-2.21}$	$^{+1.62}_{-4.31}$
$K^0_S\pi^0$ S wave	17.29	1.34	2.01	0.49	2.07	$^{+0.63}_{-3.75}$	$^{+2.58}_{-0.59}$	$^{+2.66}_{-3.80}$

Final Results



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

- $$r = \frac{Br(Ks\pi\pi 0)}{Br(K\pi\pi)} \times 2 \times 2$$

  PDG2012: 3.06±0.14

Statistical error only

Mode	BESIII	CLEO-c	r
K*bar(892)π+	3.58±0.17	11.2±0.2	3.13±0.16
K*0bar(1430)π+	3.7±0.6	10.4±0.6	2.8±0.5

- The results are consistent with CLEO-c.

Resonance Parameter

Resonance	Parameter (MeV)		BES-III	E791 Model C	CLEO-c Model C	CLEO-c Model I2
$\overline{K}^*_0(1430)$	BW	Mass	$1464 \pm 6 \pm 9^{+9}_{-28}$	1459 ± 14	$1463.0 \pm 0.7 \pm 2.4$	$1466.6 \pm 0.7 \pm 3.4$
		Width	$190 \pm 7 \pm 11^{+6}_{-26}$	175 ± 17	$163.8 \pm 2.7 \pm 3.1$	$174.2 \pm 1.9 \pm 3.2$
PDG	Flatt	Mass	1482 ± 10		1462.5 ± 3.9	1471.2 ± 0.8
1425 ± 50		$g_{K\pi}$	585 ± 14		532.9 ± 8.5	546.8 ± 4.2
270 ± 80		$g_{K\eta}$	0		0	0
		$g_{K\eta'}$	452 ± 85		197 ± 106	230 ± 32
κ	BW	Mass	860 ± 11	797 ± 47	809 ± 14	888 ± 2
		Width	446 ± 23	410 ± 97	470 ± 18	550 ± 12
	Pole	Re	$752 \pm 15 \pm 69^{+55}_{-73}$		769.9 ± 6.3	$706.0 \pm 1.8 \pm 22.8$
		Im	$-229 \pm 21 \pm 44^{+40}_{-55}$		-221.2 ± 8.4	$-319.4 \pm 2.2 \pm 20.2$

BESIII Preliminary

PRL 89, 121801(2002)

PRD 78, 052001(2008)

- The mass and width of K*0(1430) are consistent with E791 and CLEO-c from $D^+ \to K^- \pi^+ \pi^+$.
- 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.
- The pole of κ(800) is consistent with the model C of CLEO-c.

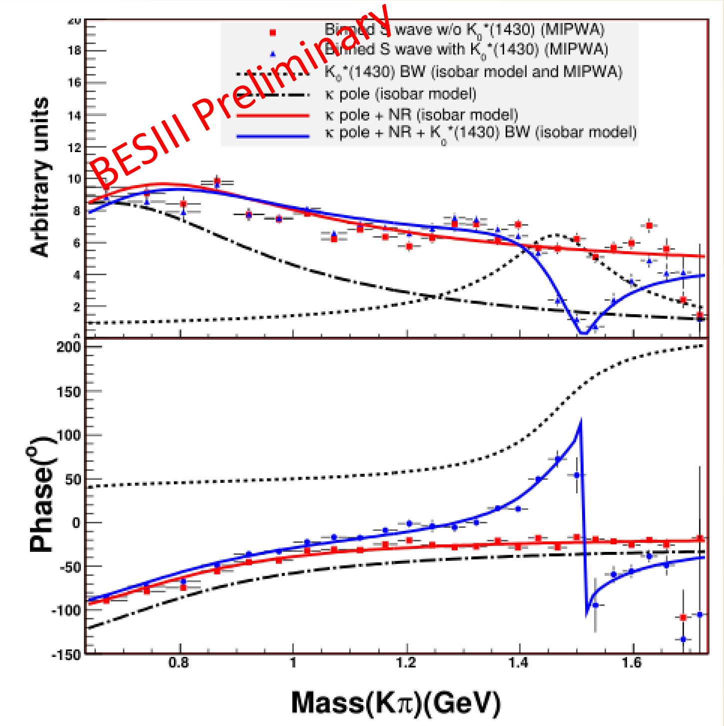
Cross-check with Model-Independent PWA

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

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

  - First by E791 PRD 73,032004(2006)

- The K*0bar(1430) is destructive interfered with κ(800) and non-resonant, which can explain the fraction of Kπ S wave smaller than the combine of κ(800) and non-resonant.
- The phase shift can be described by NR+κ(800) well.



Summary

- 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 κ) 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±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.

Mode	Partial Branching Fraction (%)	PDG 2012:
$B(D^+ \to K_S^0 \pi^+ \pi^0)$ Non Resonant	$0.32 \pm 0.05 \pm 0.25^{+0.21}_{-0.25}$	0.9 ±0.7
$B(D^+ \to \rho^+ K_S^0) \times B(\rho^+ \to \pi^+ \pi^0)$	$5.83 \pm 0.16 \pm 0.30^{+0.08}_{-0.15}$	4.7±1.0
$B(D^+ \to \rho(1450)^+ K_S^0) \times B(\rho(1450)^+ \to \pi^+ \pi^0)$	$0.15 \pm 0.02 \pm 0.09^{+0.05}_{-0.11}$	
$B(D^+ \to \overline{K}^*(892)^0 \pi^+) \times B(\overline{K}^*(892)^0 \to K_S^0 \pi^0)$	$0.250 \pm 0.012 \pm 0.015^{+0.022}_{-0.024}$	1.3±0.6
$B(D^+ \to \overline{K}_0^*(1430)^0 \pi^+) \times B(\overline{K}_0^*(1430)^0 \to K_S^0 \pi^0)$	$0.26 \pm 0.04 \pm 0.05^{+0.03}_{-0.06}$	
$B(D^+ \to \overline{K}^*(1680)^0 \pi^+) \times B(\overline{K}^*(1680)^0 \to K_S^0 \pi^0)$	$0.09 \pm 0.01 \pm 0.05^{+0.04}_{-0.08}$	
$B(D^+ \to \overline{\kappa}^0 \pi^+) \times B(\overline{\kappa}^0 \to K_S^0 \pi^0)$	$0.54 \pm 0.09 \pm 0.28^{+0.14}_{-0.19}$	
NR+$\overline{\kappa}^0 \pi^+$	$1.30 \pm 0.12 \pm 0.12^{+0.11}_{-0.30}$	
$K_S^0 \pi^0$ S wave	$1.21 \pm 0.10 \pm 0.16^{+0.05}_{-0.27}$	

BESIII Preliminary

Thank you for your attention!