Study for Dalitz Analysis on $D^+ \to K^0{}_S \pi^+ \pi^0$ at BES-III

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Charm@Threshold 2011
2011/10/22

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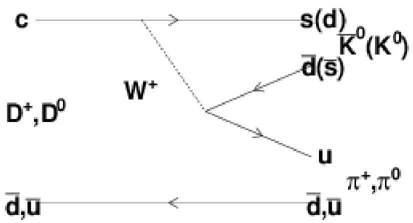
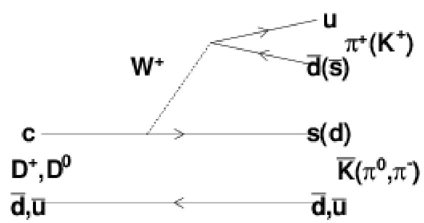
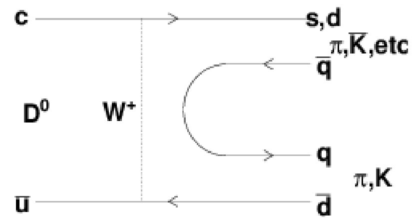
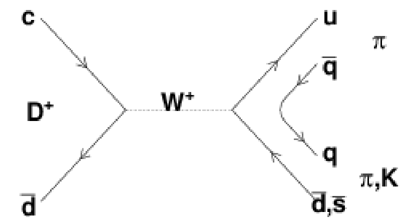
Motivation









- In D meson decay, there are several interacting phenomena including Cabibbo suppressed processes. Through Dalitz plot analysis, we can measure their relative branching fraction to understand the dynamics of two body charmed meson decay.

- $K\pi$ S wave and low-mass $K\pi$ scalar resonance κ have been observed significantly in earlier experiments (MARKIII, NA14, E691-791, CLEO) through dalitz plot analysis.

- BES-III have taken huge data at charm threshold. Before perform Dalitz analysis on data, MC study in necessary. $D^+ \to K_s \pi^+ \pi^0$ is a good channel to measure $K\pi$ S wave, because $D^+ \to \kappa^+ \pi^0$ is doubly Cabbibo suppressed.

MC Sample

	Generator	Events
DD	EvtGen	105,600,000
qq	LUNDA	48,800,000
Uniform $Ks\pi^+\pi^0$	PHSP	5,000,000
Dalitz $Ks\pi^+\pi^0$	User defined Dalitz	5,000,000
		50,000
		50,000
		etc.

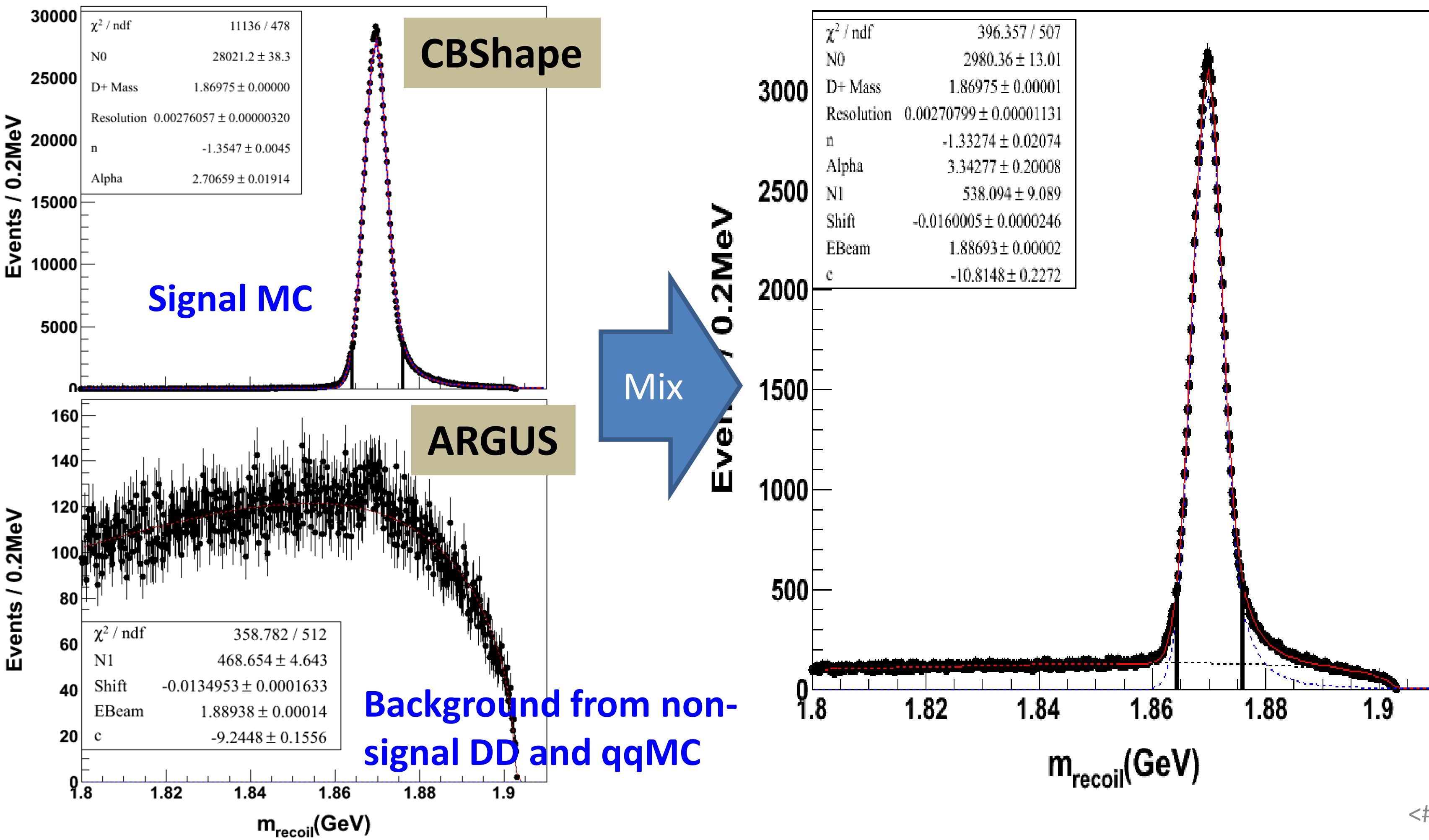
BES-III MC simulation (BOOST) is based on Geant4.

Event Selection

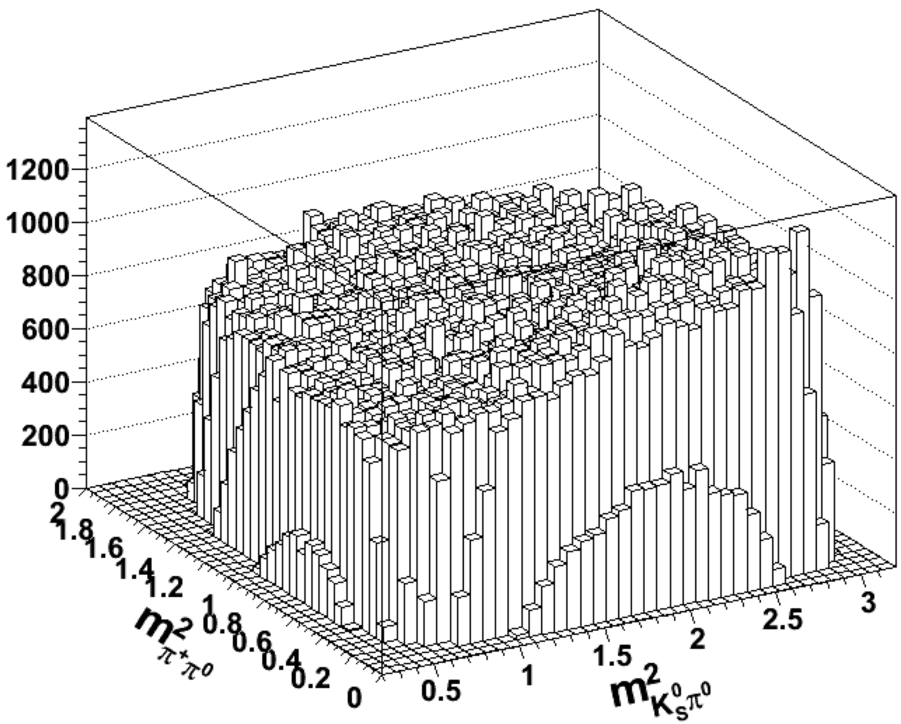
- **Particle ID for two π^+, one π^- and two photon candidates**
- **Kinematic fit:**
  - π^0, K^0_S and D^+ masses constrained
  - loop all combinations, and select the three candidate particles with smallest chisquare.
  - chisq<10

Signal Fraction

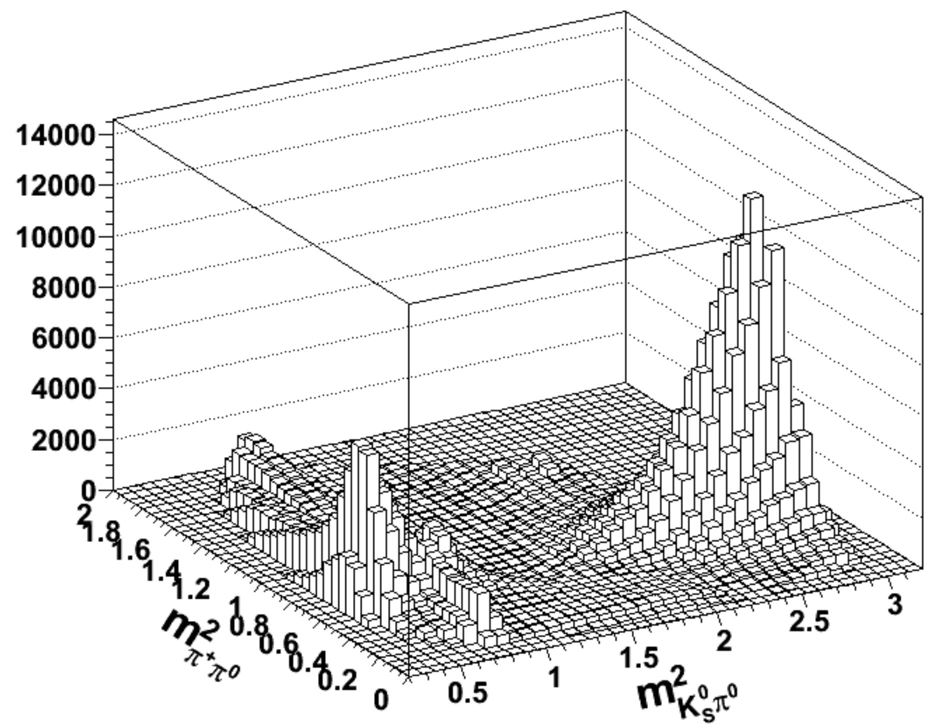
Nsig-in	Nsig-fit	Nbkg-in	Nbkg-fit	Fsig-in	Fsig-fit
257391	256466±1005	7272	8537±161	0.9725	0.9678±0.0008
132293	132058±734	7244	7647±153	0.9481	0.9453±0.0014
99201	99163±161	7238	7424±146	0.9320	0.9303±0.0018



PHSP MC



Dalitz MC



PDF

- **Defines probability density function (p.d.f.)**
  - $P(x,y)=f_{sig}N_S|M(x,y)|^2\varepsilon(x,y)+(1-f_{sig})N_B B(x,y)$
  - $N_S=1/\int|M(x,y)|^2\varepsilon(x,y)dxdy$
  - $M(x,y)$ are decay matrix elements

- **Background p.d.f.: (sideband)**
  - $P_B(x,y)=N_B B(x,y)$
  - $\int P_B(x,y)dxdy= N_B\int B(x,y)dxdy=1$

- **Efficiency p.d.f.: (Uniform MC)**
  - $P_\varepsilon(x,y)=N_\varepsilon\varepsilon(x,y)$
  - $\int P_\varepsilon(x,y)dxdy= N_\varepsilon\int\varepsilon(x,y)dxdy=1$

- **Maximum likelihood fit to optimize parameters (Fitter:Minuit)**
  - $L=-2\Sigma \log P(x_i,y_i)$

Decay Amplitude

- **The decay matrix element is sum of all intermediate resonance amplitude and non-resonance amplitude**:
  - $\mathcal{M}(D\rightarrow K\pi\pi)=c_{NR}+\Sigma\mathcal{M}_r+\mathcal{M}_\kappa$
  - Non-resonance: uniform phase space
    - $c_{NR}=a_{NR}e^{i\phi_{NR}}$
  - Resonance:
    - $\mathcal{M}_r=a_R e^{i\phi_R}A_r(abc|r)$

$$F_V^L(q)=\begin{cases}1 & L=0\\ \sqrt{\frac{1+q_V^2}{1+q^2}} & L=1\\ \sqrt{\frac{9+3q_V^2+q_V^4}{9+3q^2+q^4}} & L=2\\ \sqrt{\frac{405+45q_V^2+6q_V^4+q_V^6}{405+45q^2+6q^4+q^6}} & L=3\end{cases}$$

- **For D→Rc,R→ab, the amplitude**
  - $A_R(abc|R)=Z(J,L,l,p,q)F_R^L(r_D p)F_R^L(r_R q)T_R(ab)$, Blatt-Weisskopf form factor
  - Z describes the angular distribution of the final state
  - $T_r(ab)$: Breit-Wigner formalism
- **Formulation for Breit-Wigner resonance decaying to spin-0 particle and b:**
  - $T_R(ab)=1/(m^2_R-m^2_{ab}-im_R\Gamma_{ab}(q))$
  - $\Gamma=\Gamma_R(q/q_R)^{2L+1}(m_R/m_{ab})F_R^L(r_R q)^2$
- **κ: a Breit-Wigner function with constant width**
  - $A_\kappa(m)=1/(s_R-m^2)$, $s_R=Re+iIm$

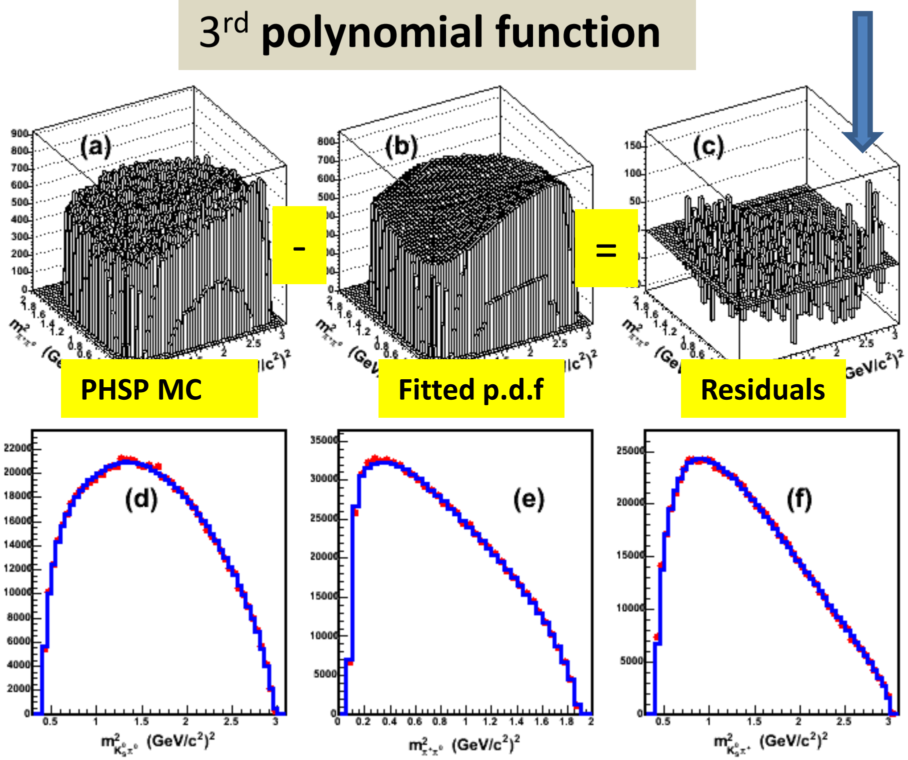
– **Fit fraction:**
  - $\int|a_R e^{i\phi_R}A_R(abc|R)|^2 dm_{ab}dm_{bc} \,/\, \int|\Sigma a_R e^{i\phi_R}A_R(abc|R)|^2 dm_{ab}dm_{bc}$

Efficiency Parameterization

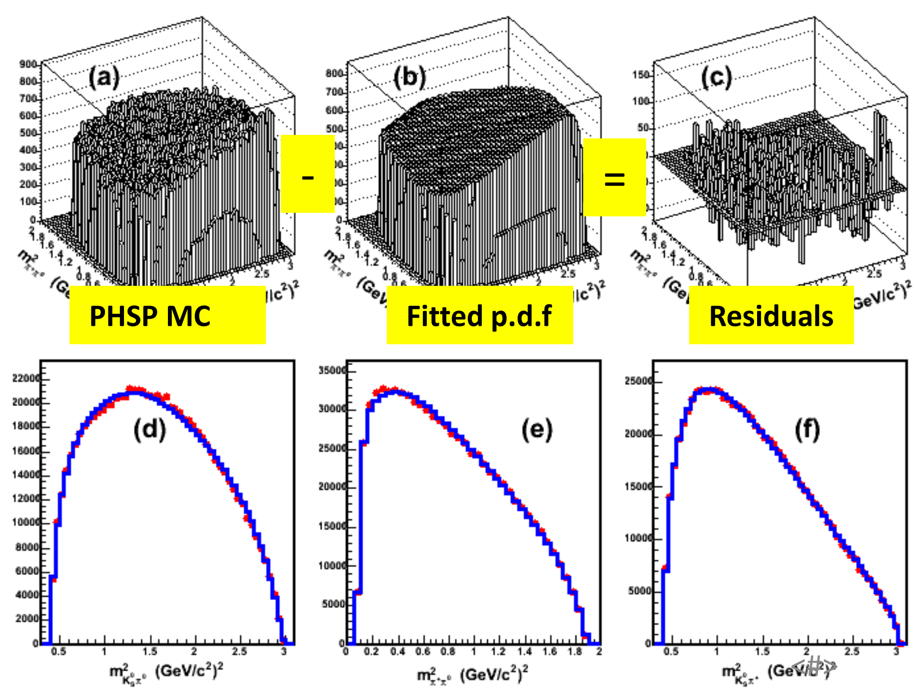
- **p.d.f. of efficiency is parameterized as polynomial multiplied threshold functions:**
  - $\varepsilon(x,y)=T(v)(1+a_x x+a_y y+a_{xx}x^2+a_{xy}xy+a_{yy}y^2+a_{xxx}x^3+a_{xxy}x^2y+a_{xyy}xy^2+a_{yyy}y^3)$
- **The threshold function is taken as a exponential form:**
  - $T(v)=a_0+(1-a_0)[1-exp(-a_{thv}|x-x_{edge}|)]$

$\chi 2/n$: **1922/1255 (3rd), 2022/1259(2nd), 2176/1262(1st)**

3rd polynomial function



1st polynomial function



Background Parameterization

p.d.f. of background is parameterized as dominant 3rd order polynomial function added by non-interfere resonance components :

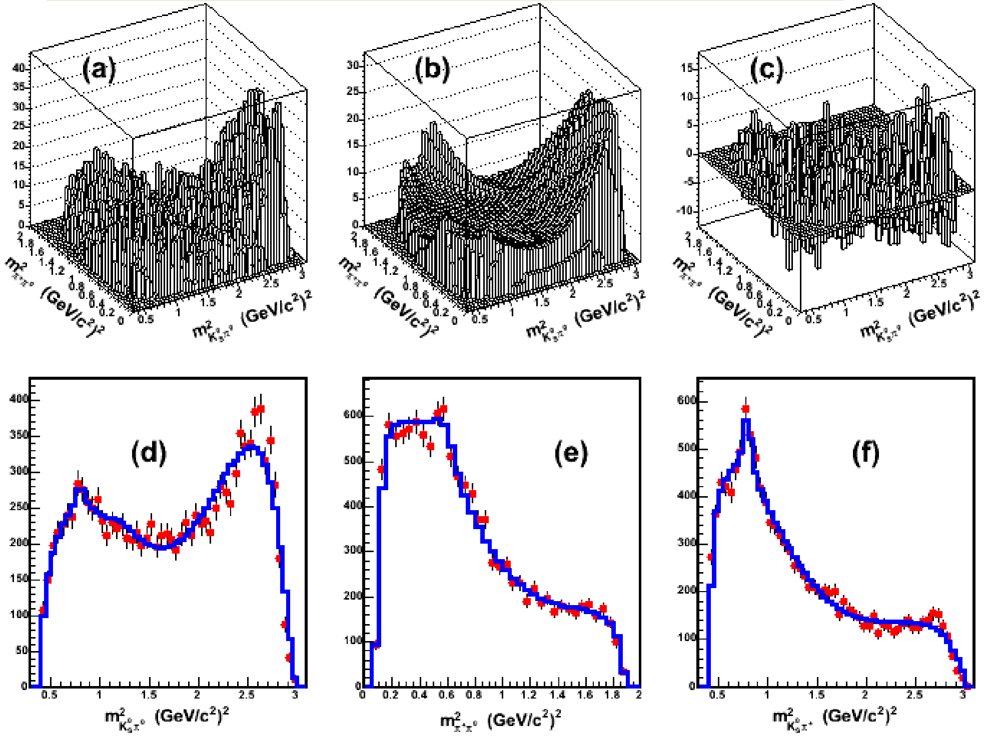
$$B(x,y)=T(v)(p3(x,y)+f_1|M(\rho 770)|^2+f_2|M(K^*(892)^+|^2+f_3|M(K^*(892)^0|^2)$$

$$p3(x,y)=1+b_x x+b_y y+b_{xx}x^2+b_{xy}xy+b_{yy}y^2+b_{xxx}x^3+b_{xxy}x^2y+b_{xyy}xy^2+b_{yyy}y^3$$

- **Dominant background source:**
  - **$D^+ \to K^0_S a_1(1260)^+$**
  - **$D^0 \to K^- \pi^+ \pi^0$**
  - **$D^0 \to K^0_S \pi^+ \pi^- \pi^0$**

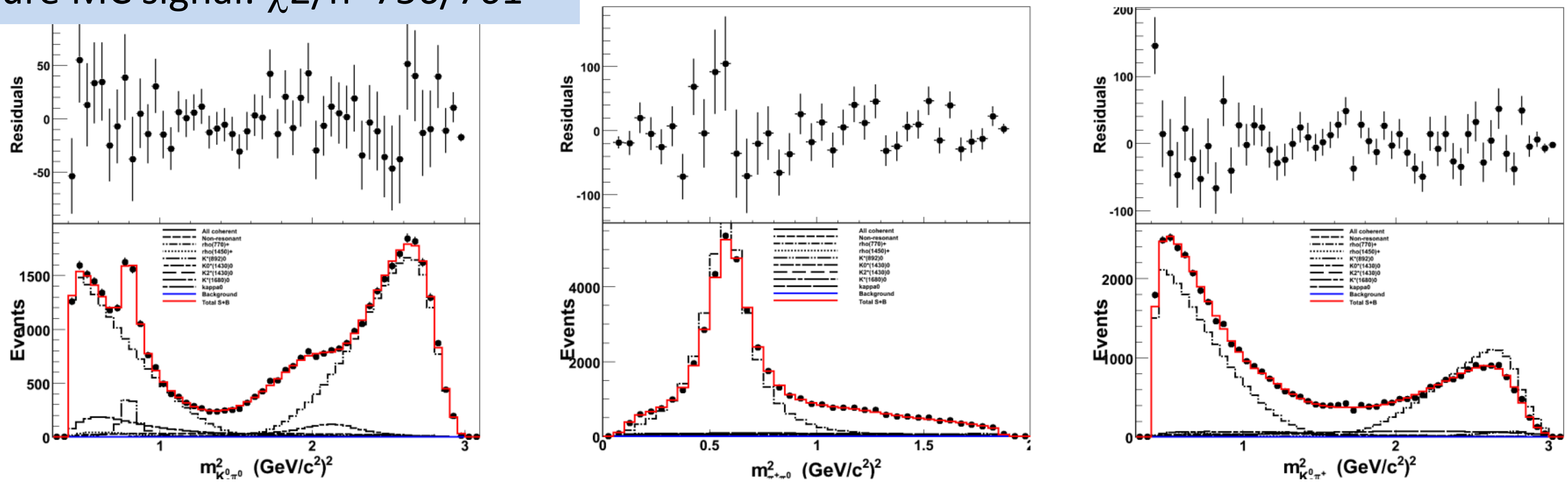
Backgrounds from D^0 bring a component of $K^*(892)^+$, and other most resonances in background are $\rho(770)$ and $K^*(892)^0$.
Hence, it is difficult to measure doubly Cabbibo suppressed channel in this case.

Example for one sideband choice(MC)

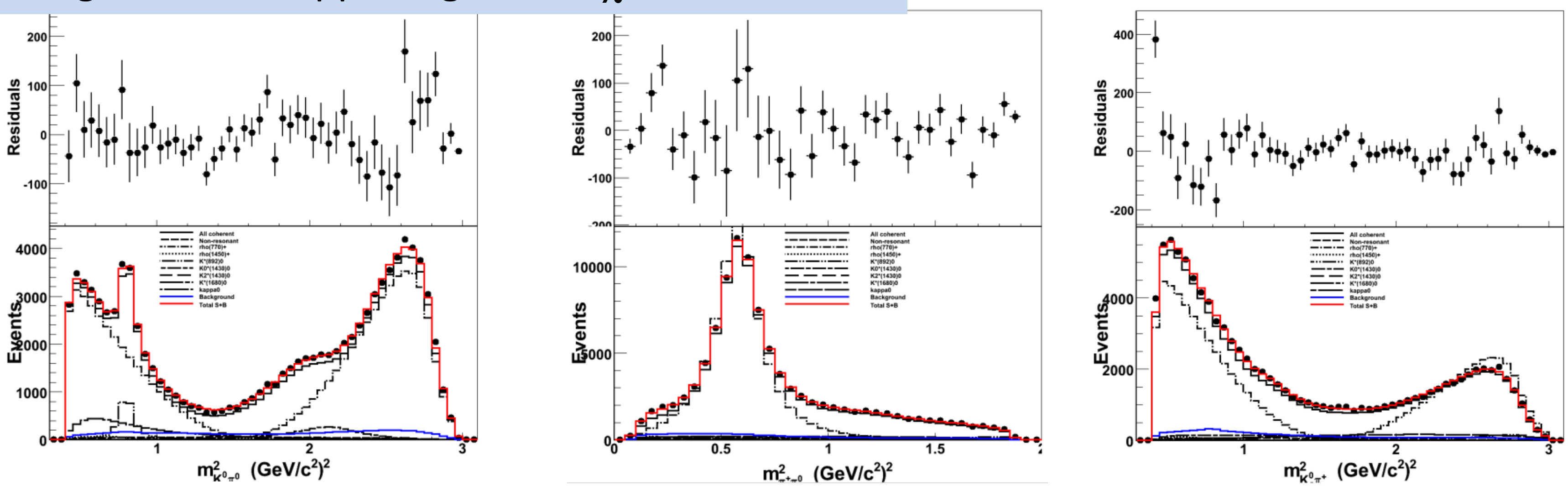


Signal Fit

pure MC signal: $\chi 2/n=756/761$



MC signal and DD,qq background: $\chi 2/n=1008/902$



Input-Output Check

- **MC sample:**
  - different mixture of intermediate resonance (by user defined DDalitz generator)
- **Initialization:**
  - same resonance choice as input
  - fixed magnitude of ρ(770) as 1, phase as 0
  - others floated from 0
- **Always the fitted results can recover amplitude within statistical error.**

An example of input amplitude and fitted amplitude(statistical error only)

Resonance	Generated		Measured	
	Amplitude	Phase (degrees)	Amplitude	Phase (degrees)
Non resonant	1.5	45	1.46 ± 0.16	58 ± 7
ρ^+	1.0	0	1.0(fixed)	0(fixed)
$\rho(1700)^+$	2.5	-90	2.2 ± 0.6	-90 ± 15
$\overline{K}^*(892)^0$	2.0	45	1.94 ± 0.04	47.6 ± 1.6
$\overline{K}_0^*(1430)^0$	1.0	-90	1.03 ± 0.09	-90 ± 7
$\overline{K}_0^*(1680)^0$	0.5	-45	0.6 ± 0.4	-40 ± 12

Toy MC Check

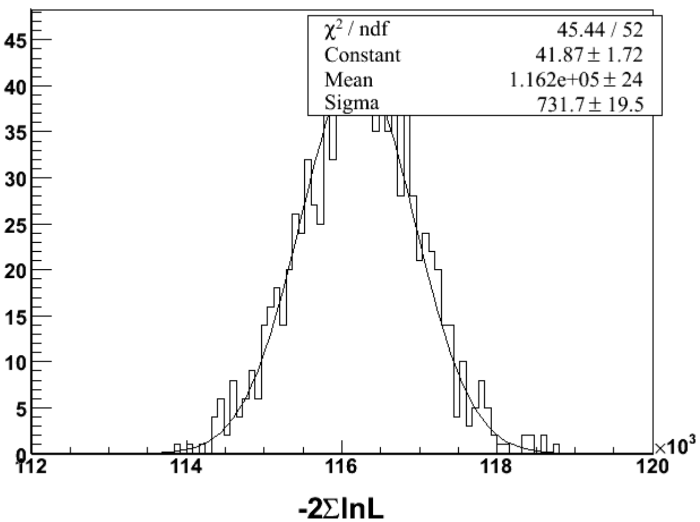
$\text{pull}=(v_{fit}-v_0)/\sigma_v$

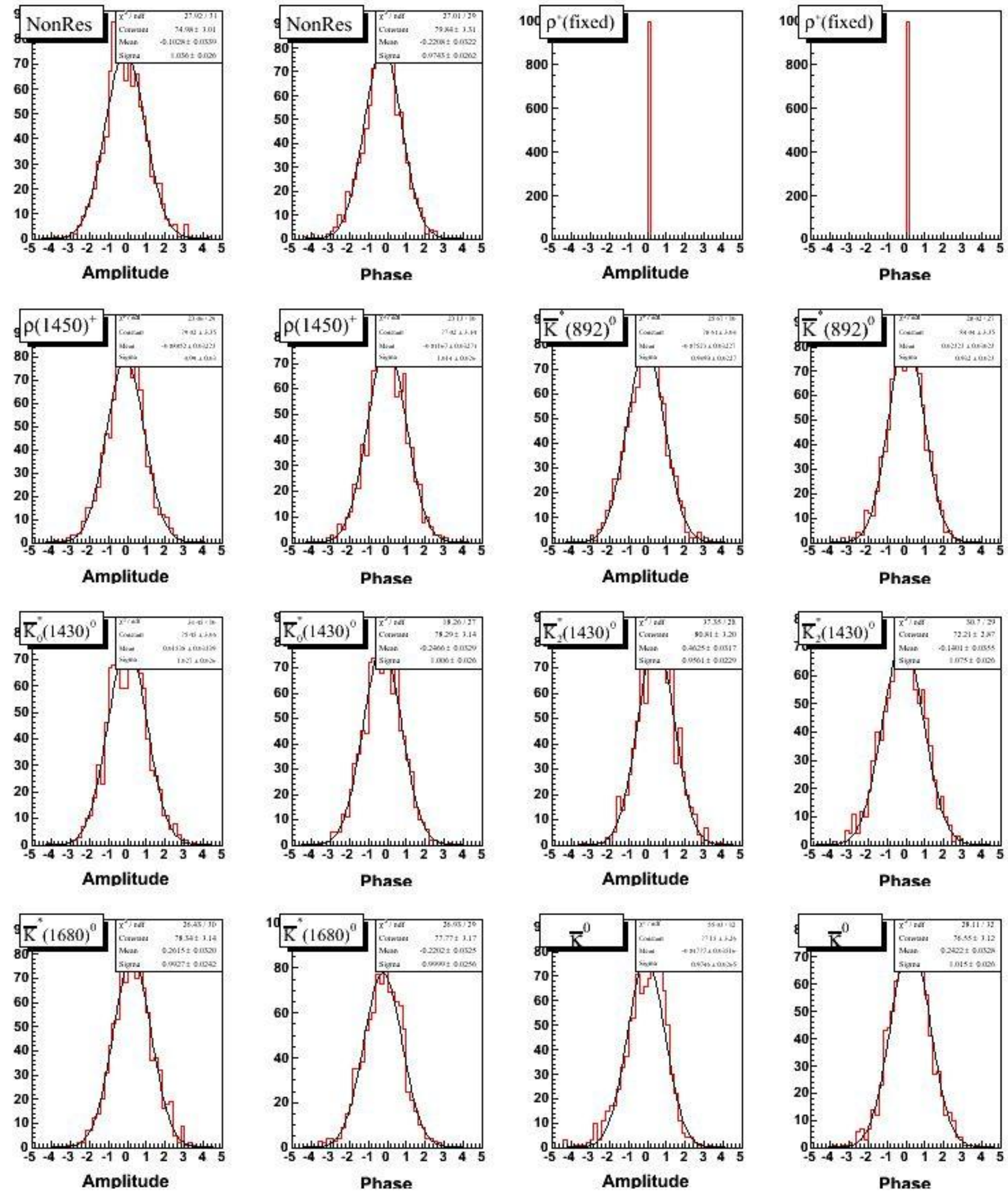
MC sample:

events: 93500

number: 1000

- The likelihood values follow a normal distribution.
- The pull values follow normal distribution, which close to (0,1).



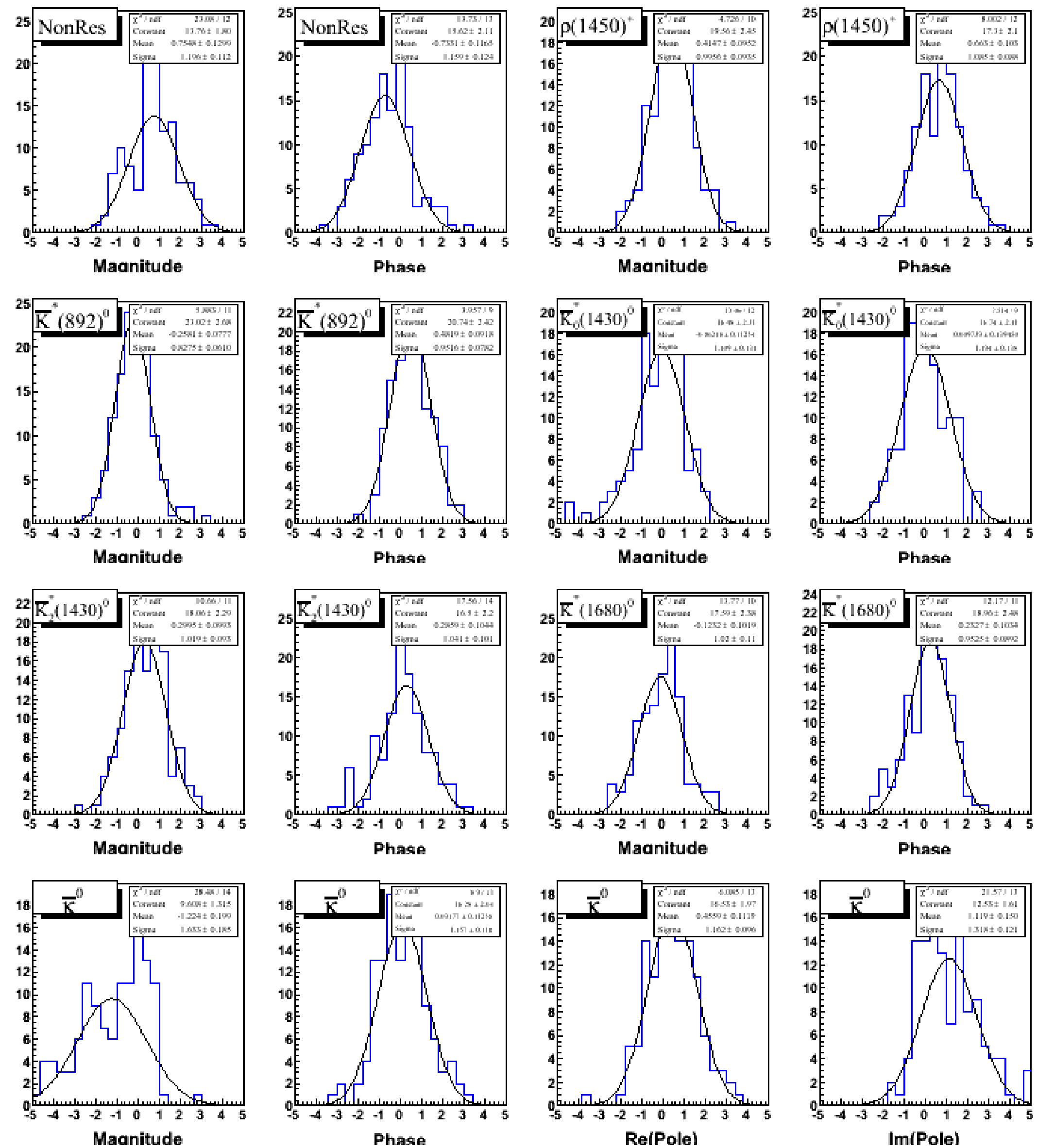


Detector MC Check

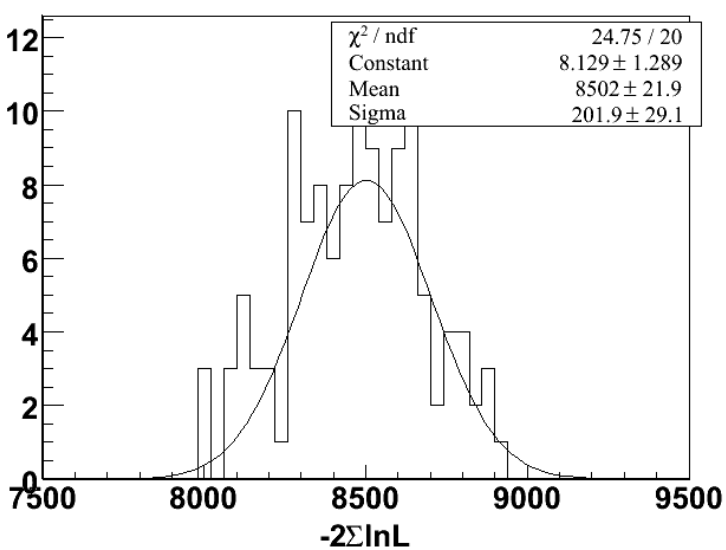
MC sample:

events: 40000(generated)

number: 125



- Most of pull distributions follow (0,1) normal distribution, but some of them become bad because of systematic affect.



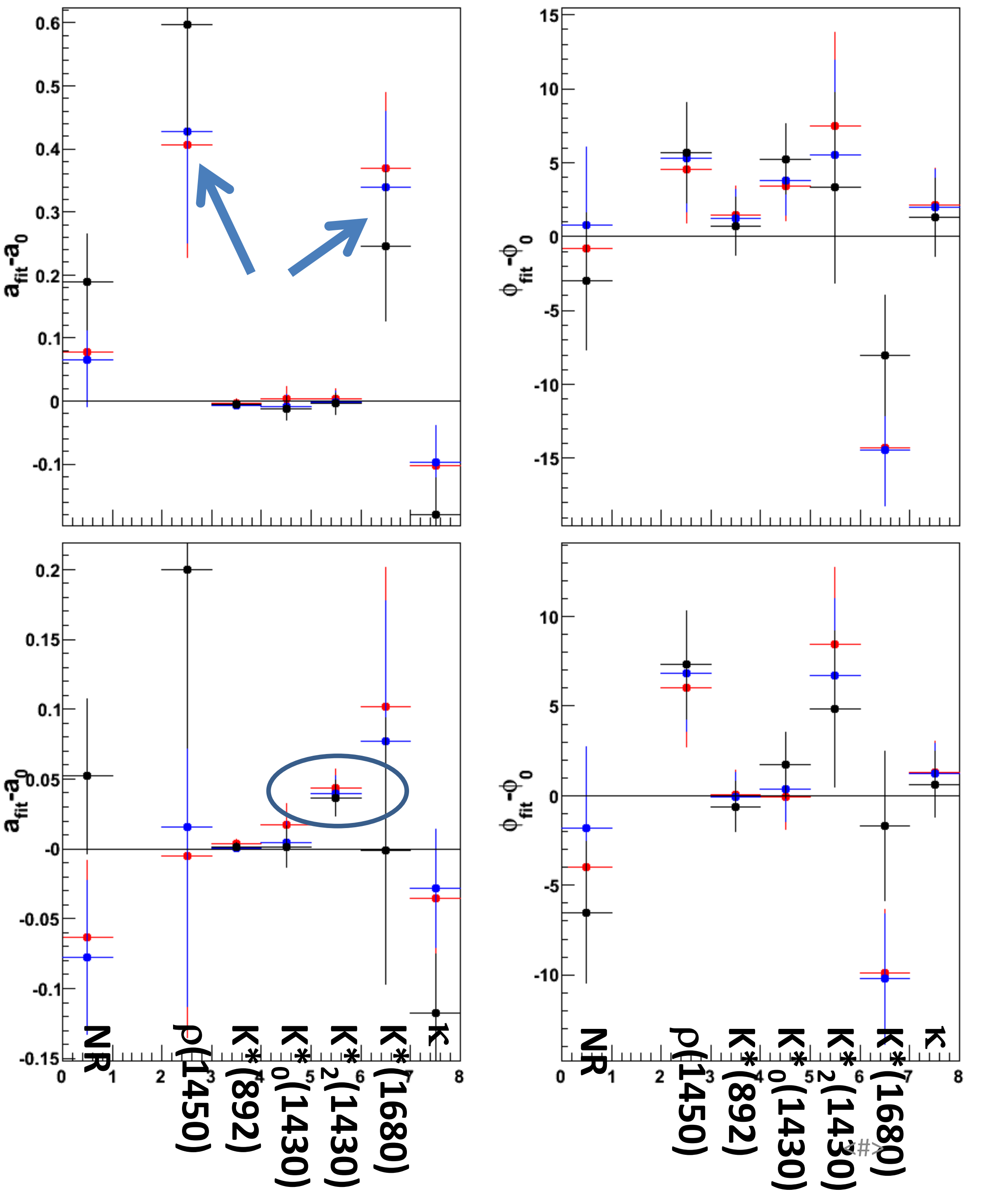
Validation

Perform different option on Dalitz plot fit, and compare the results.

- **Efficiency**
  - **different efficiency function: 1st, 2nd and 3rd polynomial**
- **Background**
  - **different sideband choice**
  - **change f_{sig}**
- **Resonance**
  - **$\rho(1450)$**
  - **$\rho(1700)$**
  - **κ:**

Efficiency

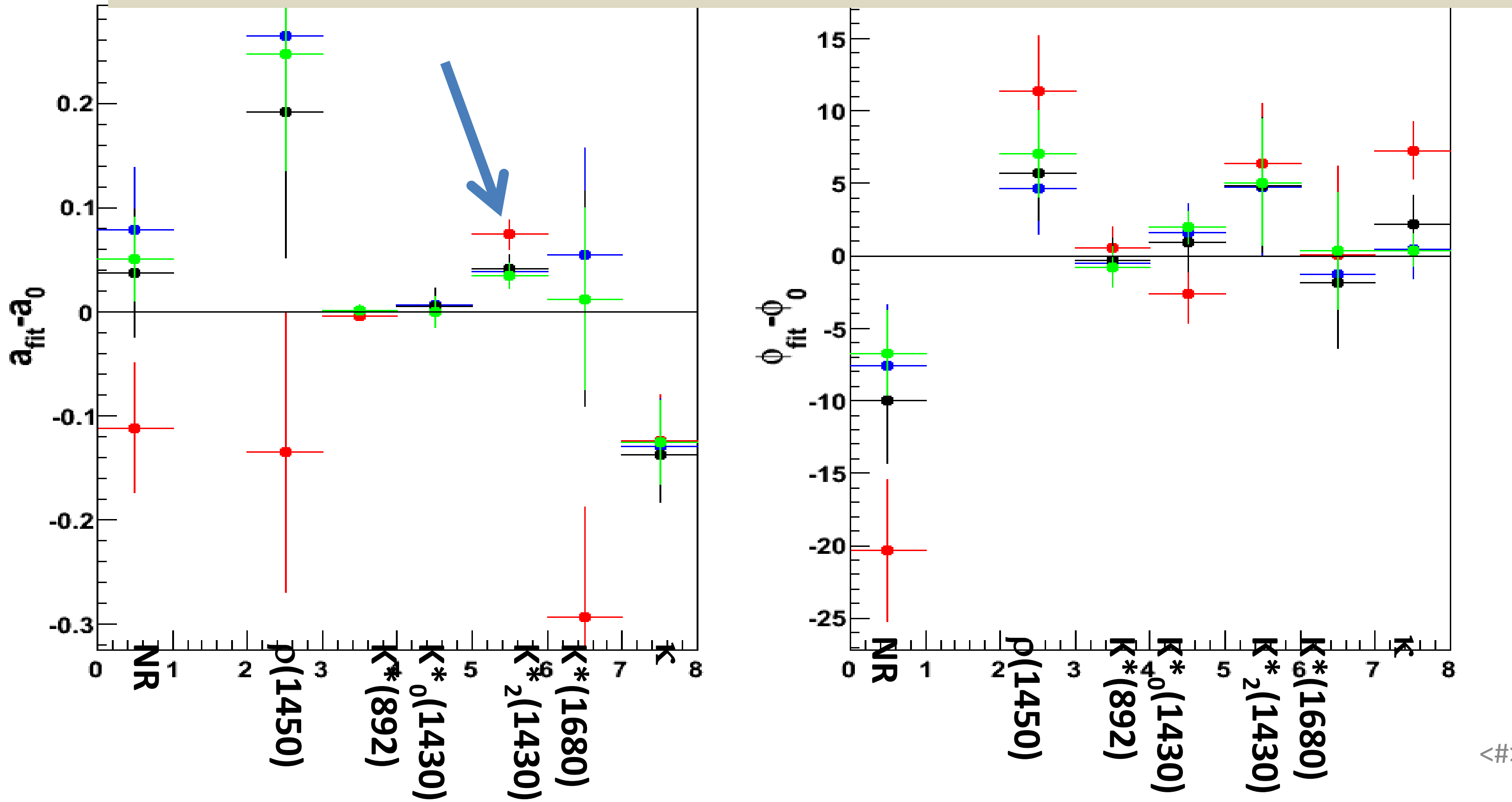
- 1st
- 2nd
- 3rd
- pure MC signal(TOP)
- mix 7% background(BOTTOM)



Background

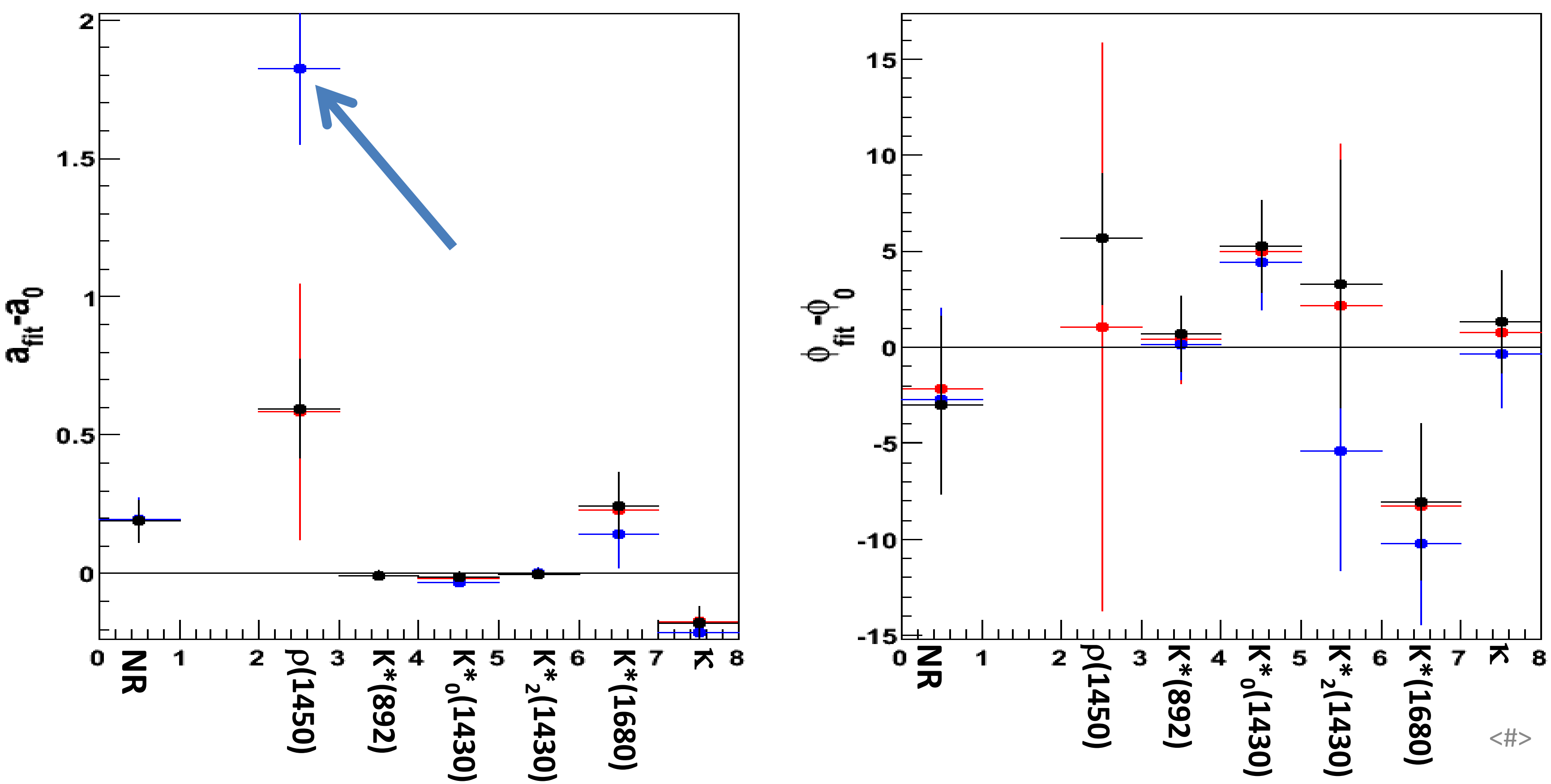
- Three sideband examples (tested more):
  1.7GeV<m_{recoil}<1.75GeV 1.8GeV<m_{recoil}<1.82GeV 1.82GeV<m_{recoil}<1.84GeV
- 3rd polynomial for efficiency is selected
- Change fsig smaller **0.5%** than real mixed value, since the systematic uncertainty is about 0.5%. (from 0.93 to 0.925 in fit)

Three sideband examples (red, black, blue) and a changed fsig case (green)



ρ(1450) and ρ(1700)

- Input:
  - ρ(1450) only and others (pure MC signal)
- Fit:
  - ρ(1450): $\chi 2/n=756/761$
  - ρ(1700): $\chi 2/n=793/756$
  - ρ(1450) and ρ(1700):

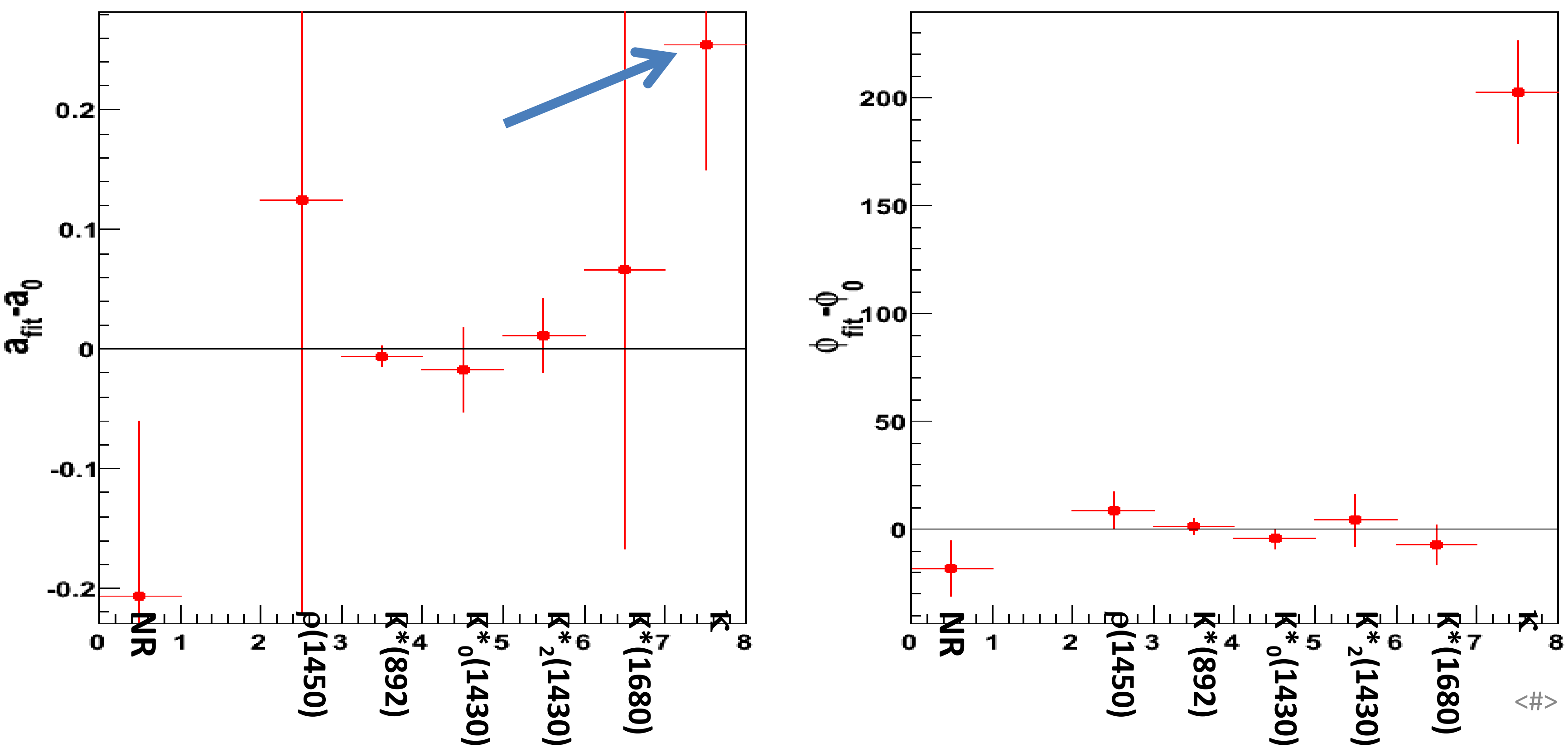


κ

- Input:
  - no κ component
- Fit:
  - include κ

Note: the statistical errors become larger

goodness become worse a little: 288/283 (without κ fit)→ 290/277 (with κ fit)



Summary

- Simulate huge MC events and perform Dalitz analysis on MC events.
- Expected resonances components can be recovered through Dalitz plot fit with statistical uncertainty at BES-III.
- The analysis is more sensitive for K*(892), $K^*_0(1430)$, $K^*_2(1430)$ than K*(1680) and heavy ρ mesons.
- Using simple 3rd polynomial function for efficiency and sideband for background, there is some systematical variation. But the variation **"seems"** un-sensitive by different choices. Because they are just few test.

Thanks!