Measurements of branching fractions of $D^0 \to K^- 3\pi^+ 2\pi^-$, $K^- 2\pi^+ \pi^- 2\pi^0$ and $D^+ \to K^- 3\pi^+ \pi^- \pi^0$

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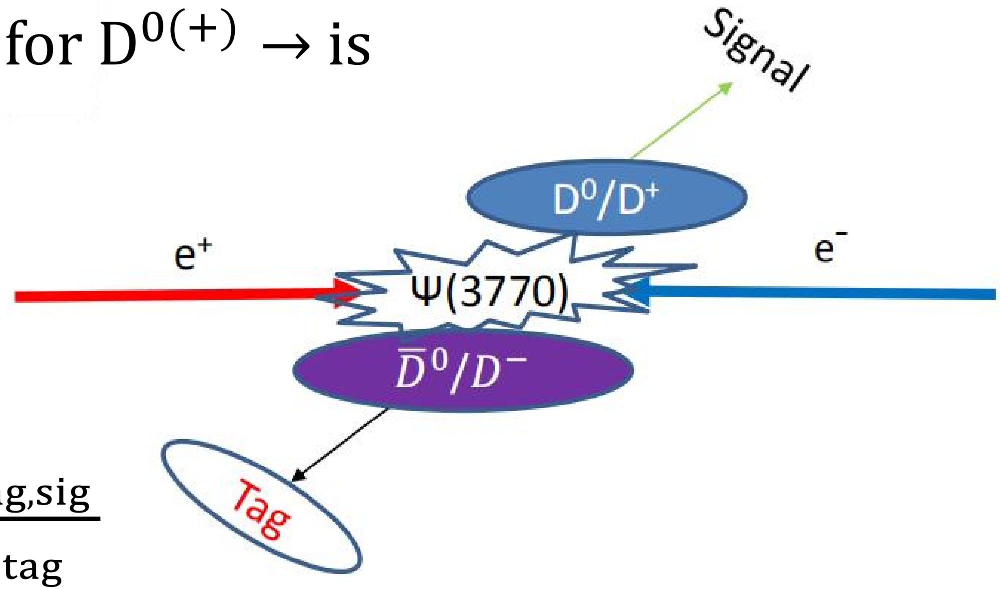
Contents

Introduction

- Since observation of D meson in 1976. The D decays have been extensively studied. But there are still many hadronic D decays unmeasured yet.
- The absolute BFs of hadronic D decays offer important input for background sources to precisely test lepton flavor universality in B physics [PLB781, 368].
- Combining the measured BFs with the results of partial wave analysis offer important information to study the quark SU(3) symmetry and its breaking effect.
- CP violation in charm decays is important to understand the asymmetry of the universe. CP violation in D decays was observed at LHCb in 2019 [PRL122, 211803].
- Our goal is to measure the BFs of unknown hadronic D decays.

Double Tag Method

- The branching fraction for $D^{0(+)} \to$ is determined by:



- $B_{sig} = \frac{N_{sig}}{N_{tag}\epsilon_{sig}}$

- $\epsilon_{tag} = \frac{N_{tag}}{N_{total}}$ $\quad \epsilon_{sig} = \frac{\epsilon_{tag,sig}}{\epsilon_{tag}}$

- N_{sig} : the number of DT events

- ϵ_{tag} : the efficiency of $\bar{D} \to$ tag

- $\epsilon_{tag,sig}$: the efficiency of $\bar{D} \to$ tag vs. $D \to$ sig

Event Selection of Single Tag events

- Good charged track (not originated from K_s^0)

  $V_{xy} < 1$ cm $\quad V_z < 10$ cm $\quad |\cos\theta| < 0.93$

- Particle Identification (dE/dx + TOF)

  $K^{\pm}$: $CL_K > CL_\pi$ && $CL_K > 0$ $\quad \pi^{\pm}$: $CL_\pi > CL_K$ && $CL_\pi > 0$

- Photon: $E_\gamma > 25$ MeV and $|cos\theta| < 0.8$ ($0.86 < |cos\theta| < 0.92$) for barrel (endcap) . $\quad 0 \leq \mathrm{TDC} \leq 14 (\times 50$ ns)

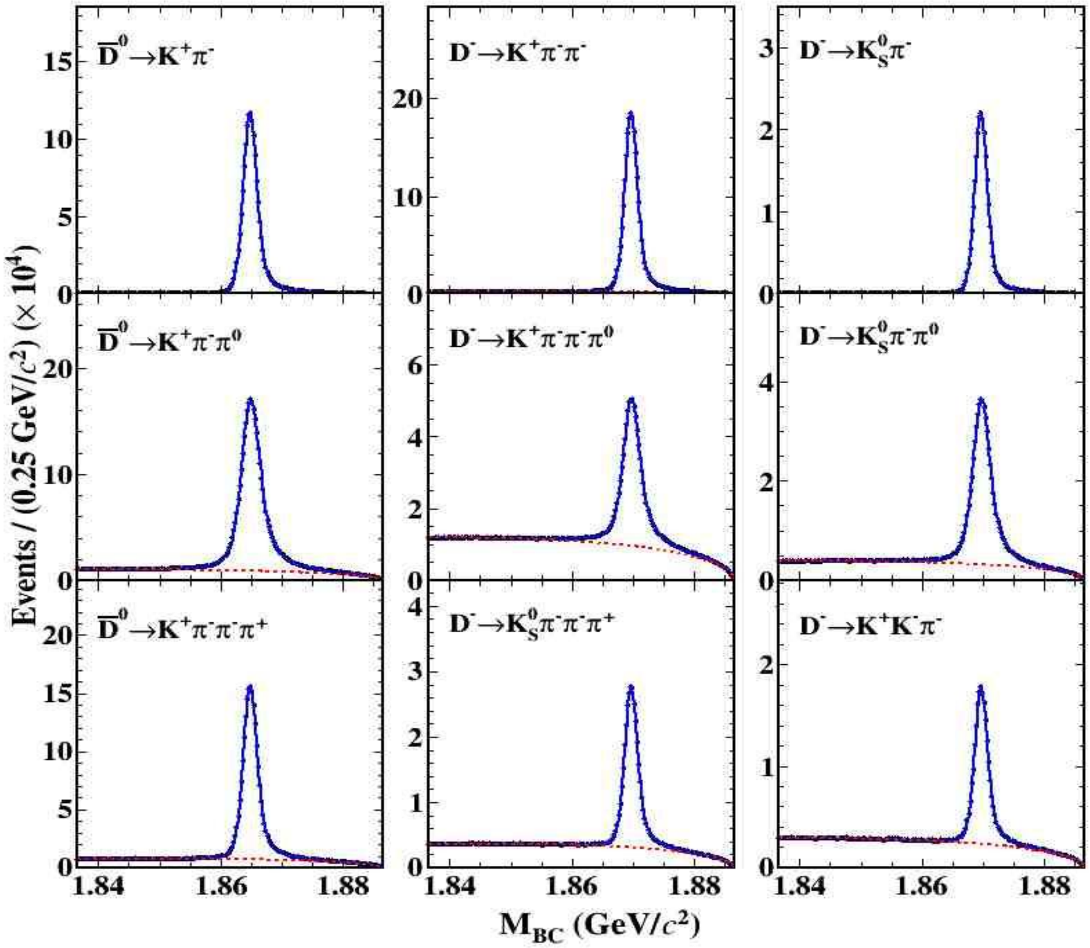
- π^0 reconstruction: $M_{\gamma\gamma}$: $(0.115 \sim 0.15)$ GeV/ c^2

  1-C kinematic fit and $\chi^2 < 50$

Single Tag

Double − Gaussian(signal) + ARGUS(BKG)

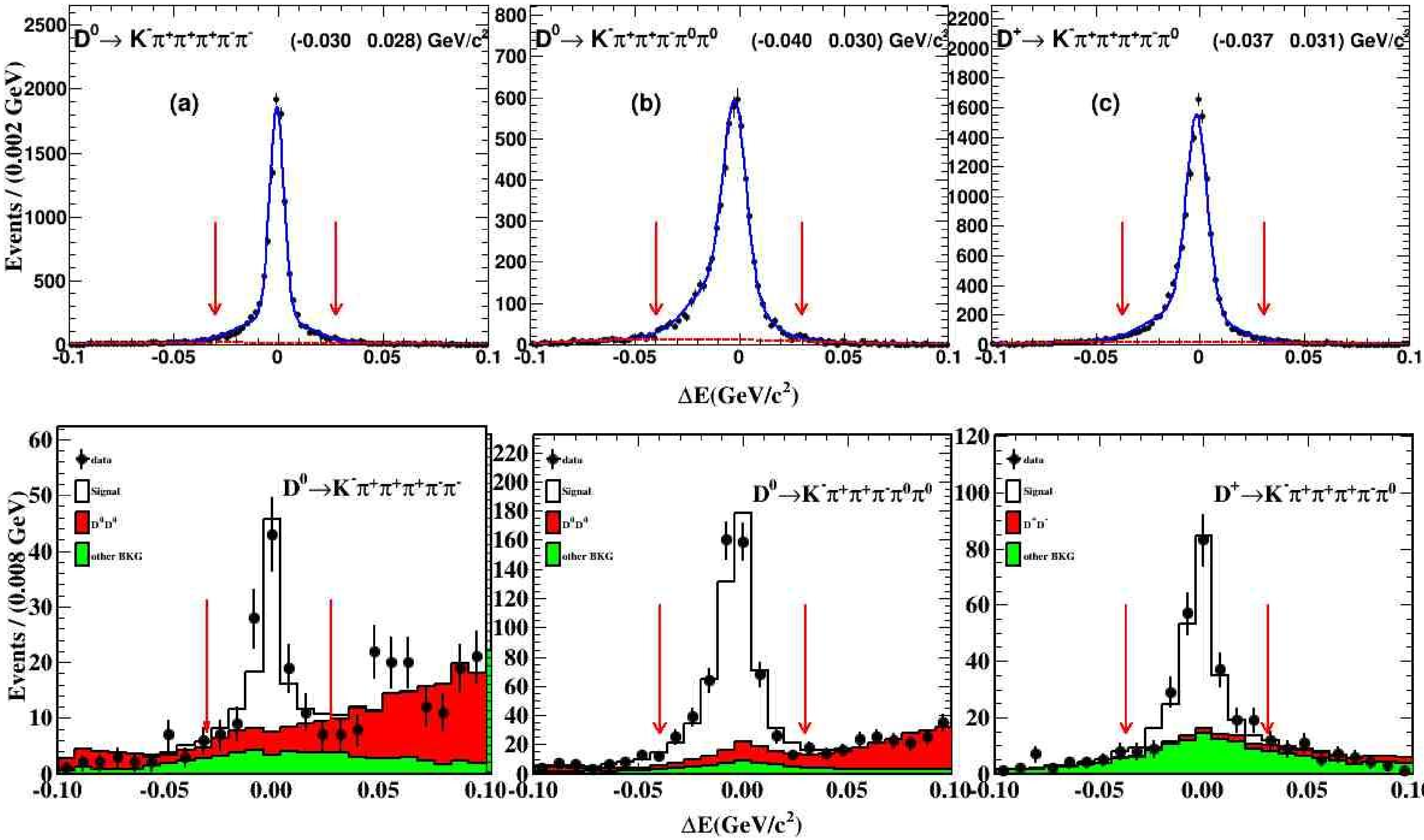
https://docbes3.ihep.ac.cn/cgi-bin/DocDB/ShowDocument?docid=1289



Cut For Fitting

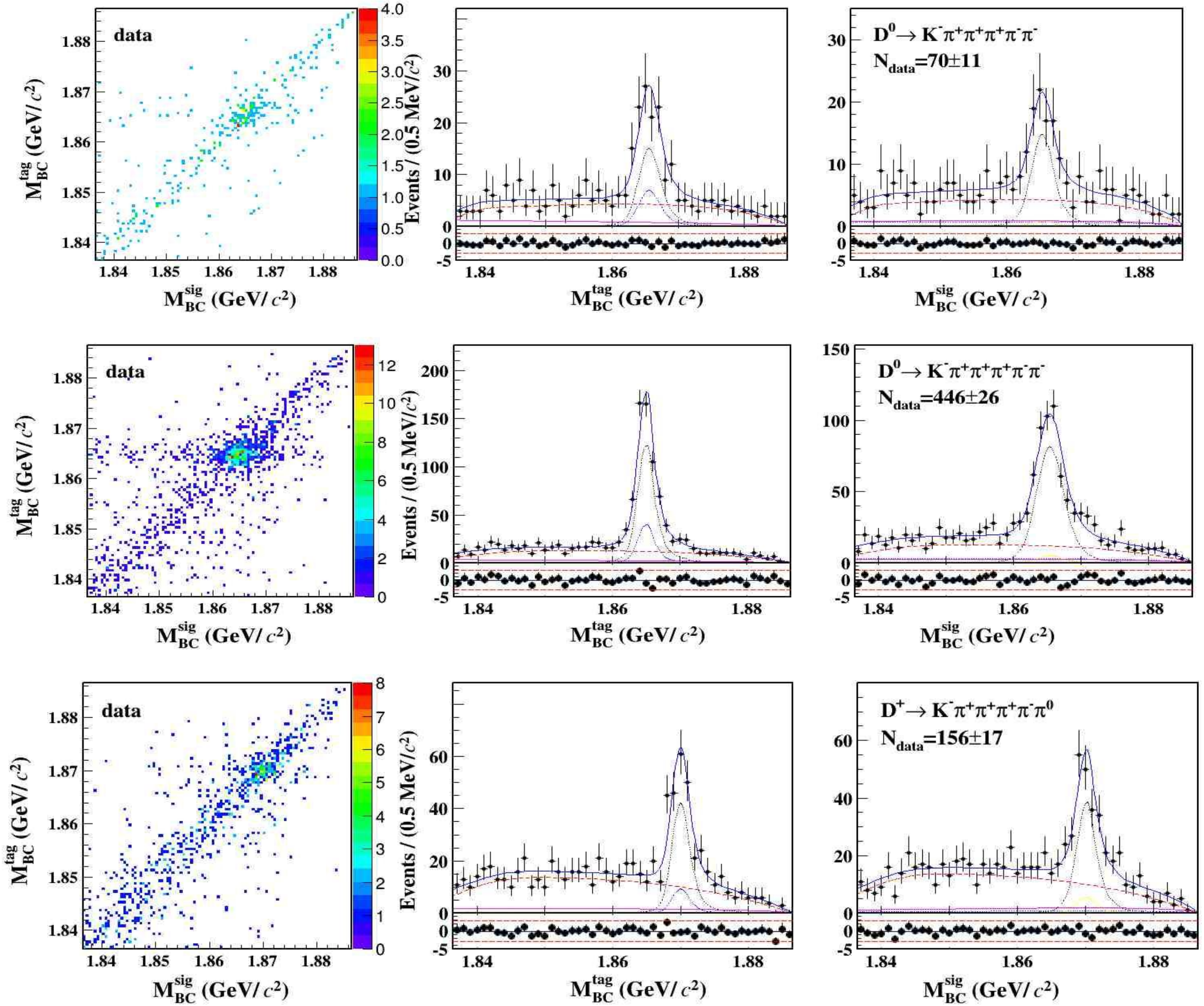
- common cut
  - $|\Delta E_{tag}| \in 3.5\sigma$ $\theta_{D\bar{D}} > 160°$
  - $|M^{sig}_{\pi^+\pi^-}$-0.4977|>0.02Gev/c^2
- Additional cut for fitting ΔE_{sig}
  - For D0,1.859 Gev/c^2<$M^{tag(sig)}_{BC} < 1.873\ Gev/c^2$
  - For D+,1.863 Gev/c^2<$M^{tag(sig)}_{BC} < 1.877\ Gev/c^2$
- Additional cut for fitting M^{sig}_{BC}
  - $\Delta E_{sig} \in 3\sigma$
- Additional cut for fitting others
  - $\Delta E_{sig} \in 3\sigma$
  - For D0,1.859Gev/c^2<$M^{tag(sig)}_{BC} < 1.873Gev/c^2$
  - For D+,1.863Gev/c^2<$M^{tag(sig)}_{BC} < 1.877Gev/c^2$

Fitting ΔE_{sig} at 3σ Signal Region

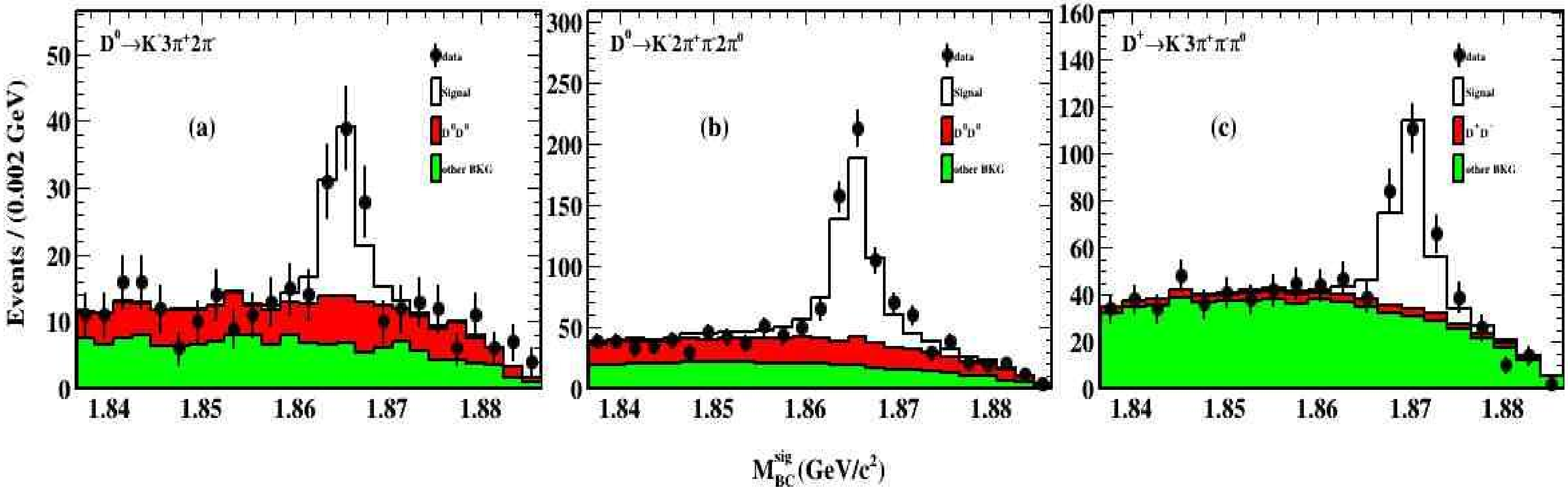


Fitting M_{BC}^{sig}

Signal shape⊗ Gaussian (signal) +ARGUS (background)



Data/MC Consistence of M_{BC}^{sig}



Decay Modes

$D^0 \rightarrow K^-3\pi^+2\pi^-$ (100%)

$D^0 \rightarrow K^-2\pi^+\pi^-2\pi^0$ (40%)

$\rightarrow K^-\pi^+\pi^0\eta$ (44%)

$\rightarrow K^{*0}\pi^+\pi^-2\pi^0$ (16%)

$D^0 \rightarrow K^-\pi^+\pi^0\eta$ quate from PDG values.

$D^+ \rightarrow K^-3\pi^+\pi^-\pi^0$ (13%)

$\rightarrow K^-\pi^+\pi^+\eta$ (33%)

$\rightarrow K^-\pi^+\pi^+\omega$ (3%)

$\rightarrow K^{*0}\pi^+\omega$ (51%)

$D^+ \rightarrow K^-\pi^+\pi^+\eta$ quate from PDG values.

Efficiency

$D^0 \to K^-\pi^+\pi^+\pi^+\pi^-\pi^-$

Tag modes	N_{gen}	N^{sig}_{obs}	$\epsilon_{tag}(\%)$	$\epsilon_{tag,sig}(\%)$	$\epsilon_{sig}(\%)$	Weight
$K^+\pi^-$	100000	5591 ± 75	66.89 ± 0.01	5.59 ± 0.09	8.36 ± 0.13	
$K^+\pi^-\pi^0$	100000	2759 ± 53	37.67 ± 0.00	2.76 ± 0.08	7.32 ± 0.22	7.32 ± 0.12
$K^+\pi^-\pi^-\pi^0$	100000	2742 ± 52	41.8 ± 0.01	2.74 ± 0.08	6.55 ± 0.19	

$D^0 \to K^-\pi^+\pi^+\pi^-\pi^0\pi^0$

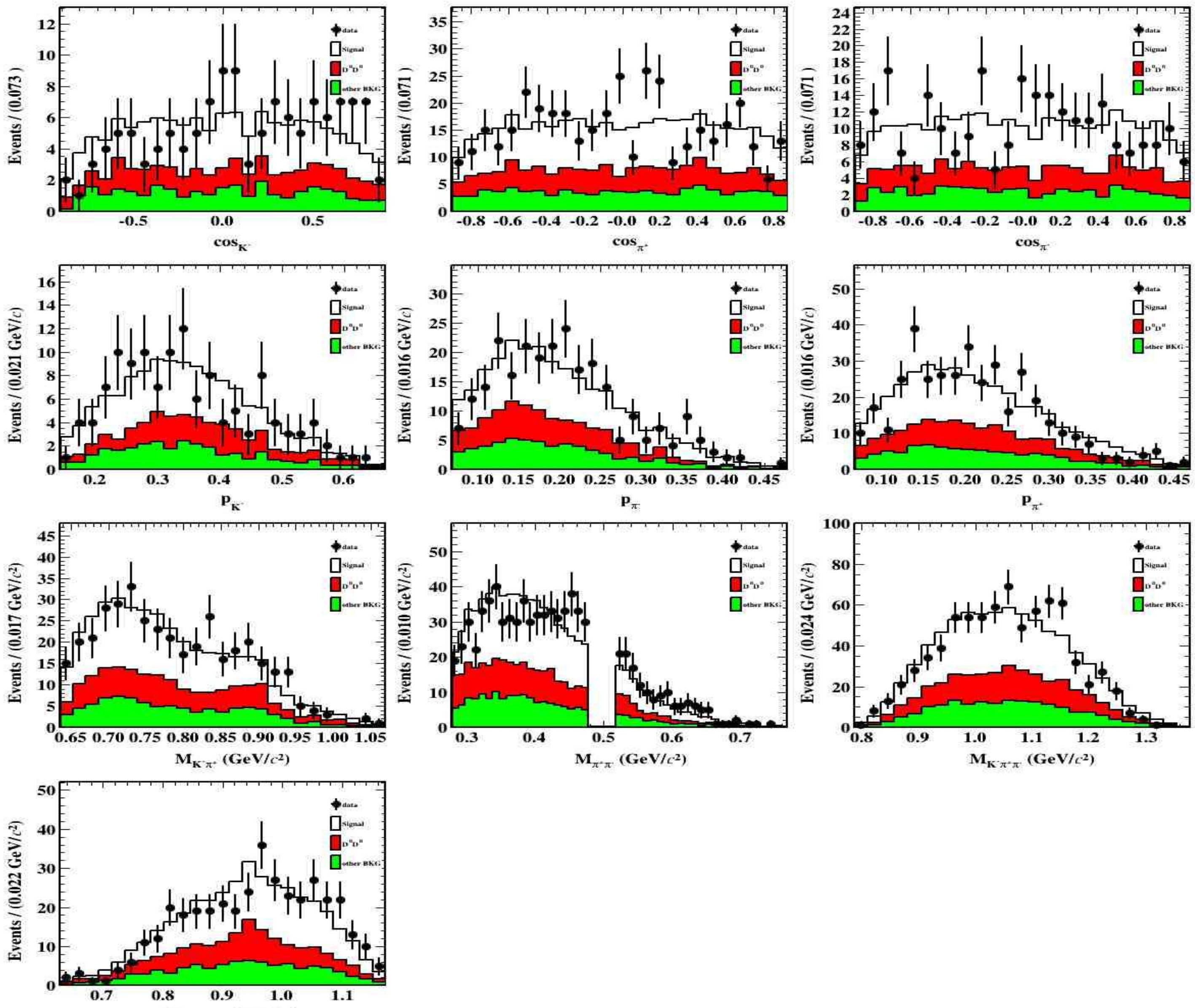
Tag modes	N_{gen}	N^{sig}_{obs}	$\epsilon_{tag}(\%)$	$\epsilon_{tag,sig}(\%)$	$\epsilon_{sig}(\%)$	Weight
$K^+\pi^-$	100000	2961 ± 54	66.89 ± 0.01	2.96 ± 0.07	4.42 ± 0.10	
$K^+\pi^-\pi^0$	100000	1349 ± 37	37.67 ± 0.00	1.35 ± 0.05	3.58 ± 0.16	3.76 ± 0.09
$K^+\pi^-\pi^-\pi^0$	100000	1484 ± 38	41.8 ± 0.01	1.48 ± 0.06	3.54 ± 0.14	

$D^+ \to K^-\pi^+\pi^+\pi^+\pi^-\pi^0$

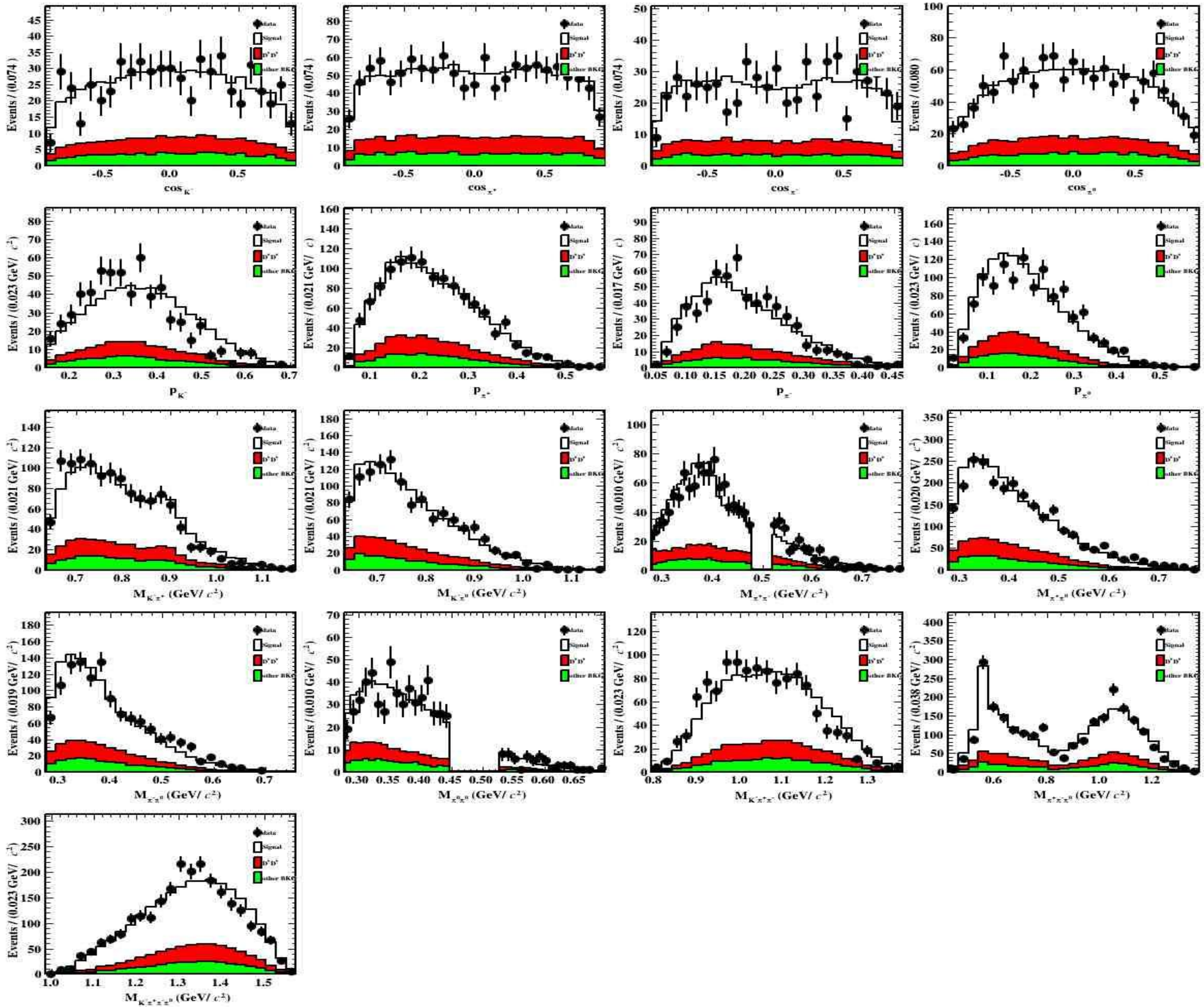
$K^+\pi^-\pi^-$	100000	3239 ± 57	52.44 ± 0.01	3.24 ± 0.08	6.18 ± 0.15	
$K^0_S\pi^-$	100000	3303 ± 57	51.89 ± 0.02	3.30 ± 0.08	6.37 ± 0.15	
$K^+\pi^-\pi^-\pi^0$	100000	1255 ± 35	27.19 ± 0.01	1.26 ± 0.07	4.62 ± 0.24	
$K^0_S\pi^-\pi^0$	100000	1463 ± 38	27.57 ± 0.01	1.46 ± 0.07	5.31 ± 0.26	5.71 ± 0.06
$K^0_S\pi^-\pi^-\pi^+$	100000	1490 ± 39	29.68 ± 0.01	1.49 ± 0.07	5.02 ± 0.23	
$K^+K^-\pi^-$	100000	2474 ± 49	42.05 ± 0.02	2.47 ± 0.07	5.88 ± 0.18	

In the case of the decay mentioned above, the final efficiency is obtained by weighting through single-tag channels.

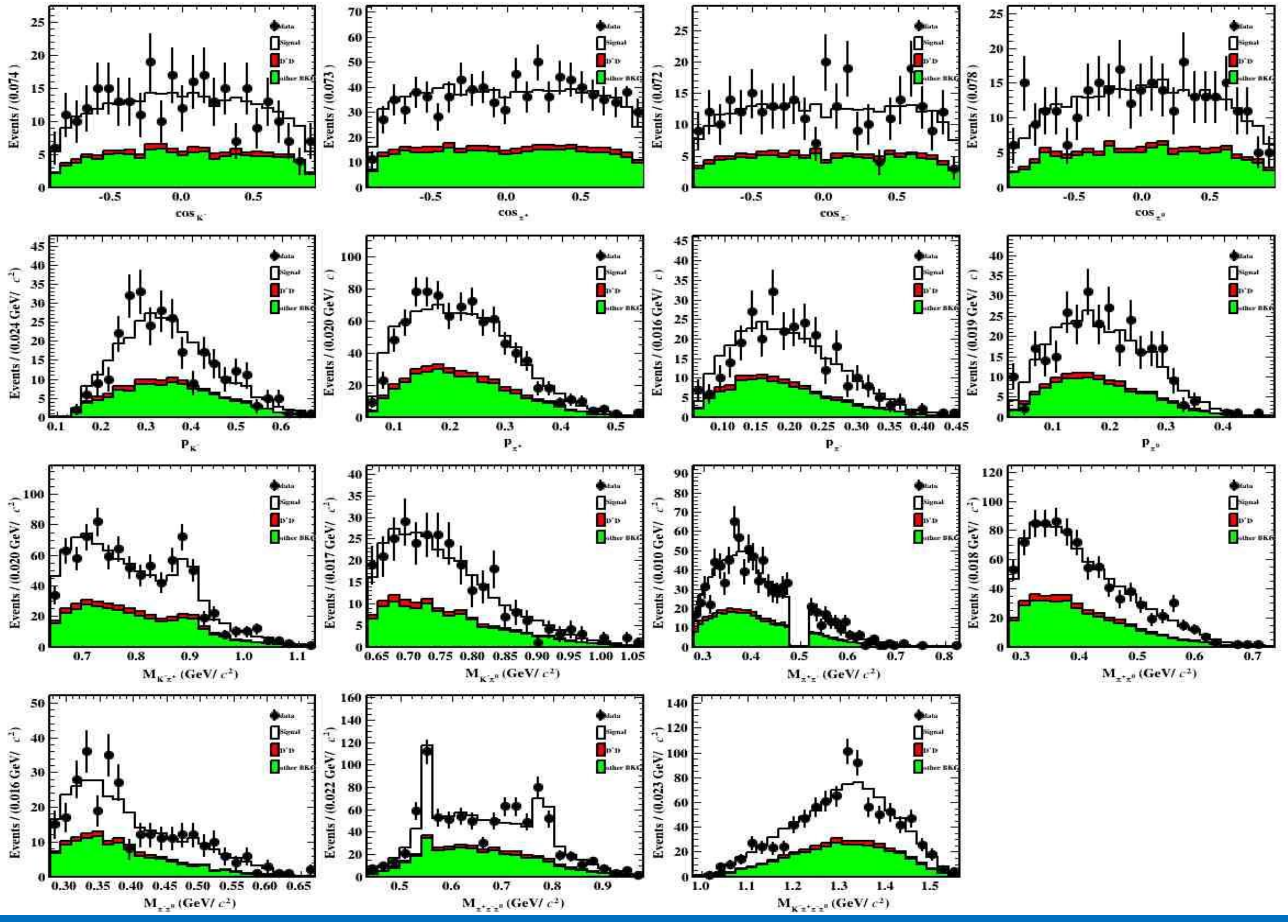
Data/MC consistence of $D^0 \rightarrow K^- 3\pi^+ 2\pi^-$



Data/MC Consistence of $D^0 \to K^-2\pi^+\pi^-2\pi^0$



Data/MC Consistence of $D^+ \to K^-3\pi^+\pi^-\pi^0$



Result of branching fraction

Decay mode	$N_{\mathrm{data,net}}$	N_{tag}	$\epsilon_{\mathrm{sig}}(\%)$	$\mathcal{B}_{\mathrm{sig}}(\times 10^{-4})$
$D^0 \to K^- 3\pi^+ 2\pi^-$	$69.8 \pm +11.4$	6598997 ± 2915	7.3 ± 0.12	1.45 ± 0.31
$D^0 \to K^- 2\pi^+ \pi^- 2\pi^0$	446.3 ± 26.0		3.8 ± 0.09	18.43 ± 2.51
$D^+ \to K^- 3\pi^+ \pi^- \pi^0$	164.2 ± 17.1	4296647 ± 2438	5.7 ± 0.06	6.77 ± 1.19

Decay mode	$\mathcal{B}_{\mathrm{sig}}^{PDG}(\times 10^{-4})$	$\mathcal{B}_{\mathrm{sig}}(\times 10^{-4})$
$D^0 \to K^- 3\pi^+ 2\pi^-$	2.2 ± 0.6	$1.45 \pm 0.23 \pm 0.08$
$D^0 \to K^- 2\pi^+ \pi^- 2\pi^0$	...	$18.43 \pm 1.07 \pm 1.44$
$D^+ \to K^- 3\pi^+ \pi^- \pi^0$	...	$6.77 \pm 0.71 \pm 0.48$

The top table shows the final results， the middle table displaying the comparison between the results and the PDG values.

Systematic Uncertainties

Tab. 11: Systematic uncertainties (%) in the measurements of the BFs for the signal decays.

Source	$D^0 \to K^-3\pi^+2\pi^-$	$D^0 \to K^-2\pi^+\pi^-2\pi^0$	$D^+ \to K^-3\pi^+\pi^-\pi^0$
N_{tag}	0.1	0.1	0.1
$(K/\pi)^\pm$ tracking	3.0	2.0	2.5
$(K/\pi)^\pm$ PID	3.0	2.0	2.5
π^0 reconstruction	–	4.0	2.0
ΔE^{sig} cut	0.7	2.4	4.0
K^0_S rejection	0.0	0.0	0.0
Quoted $\mathcal{B}$	–	0.6	0.9
MC statistics	1.7	2.3	1.7
MC generator	2.7	1.4	2.7
2D fit	0.2	0.5	1.3
Total	4.4	6.1	6.7

Relative systematic uncertainties (%) in the measurements of the BFs of D0(+) →

Systematic Uncertainties

- $N_{tag} = 0.1\%$ is quote from
Xiang Pan et al.,
https://docbes3.ihep.ac.cn/DocDB/0012/001289/002/MEMO_D_ST_v2.0.pdf

- $(K/\pi)^{\pm}$tracking and $(K/\pi)^{\pm}\mathrm{PID}$ (0.5% for each) are quote from Kaikai He et al.,
https://docbes3.ihep.ac.cn/DocDB/0012/001283/004/K_pi_tracking_pid_v1.4.pdf

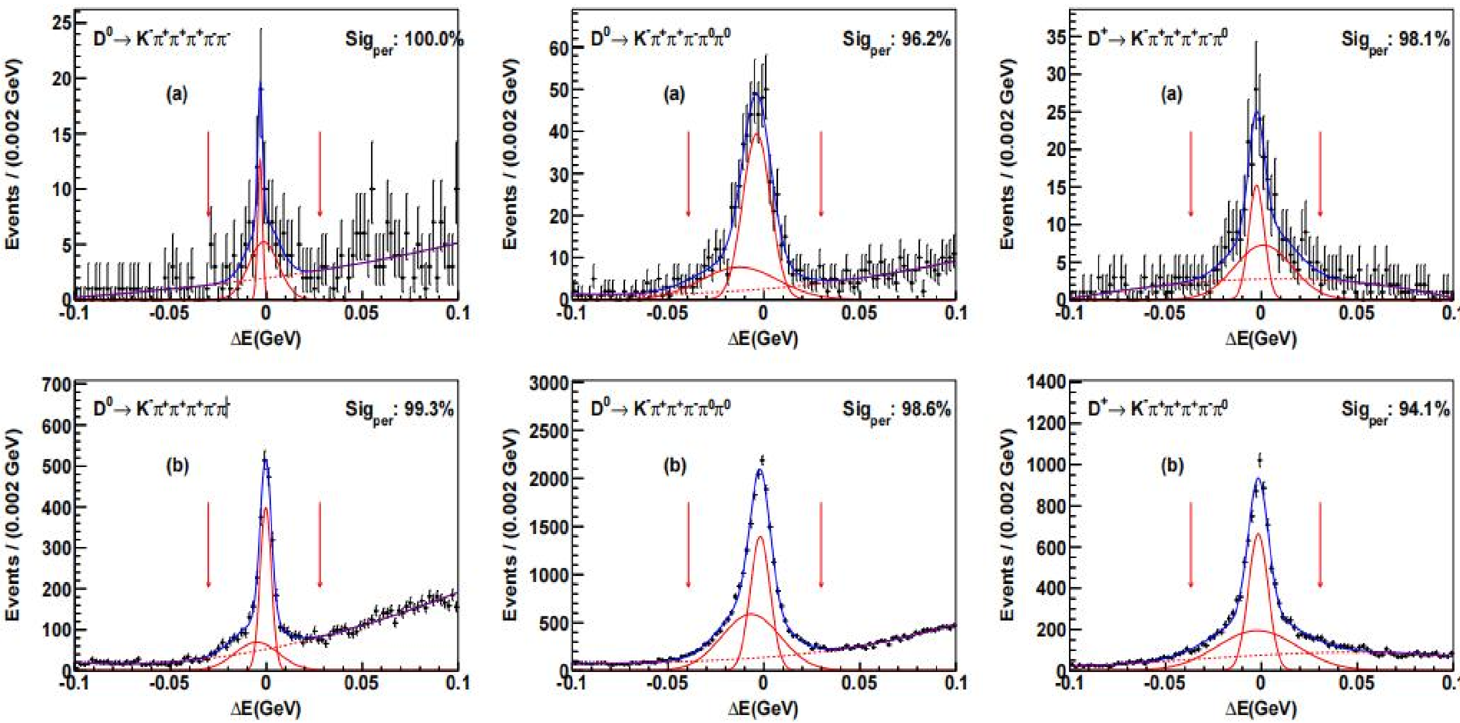
- π^0 reconsrtuction (2% for each) is quote from
Yu Lu et al.,
Pi0eff_round0304_round15_710_v0.1.pdf (ihep.ac.cn)

- Quote BF is from
P. A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022).

Systematic Uncertainties

- ΔE^{sig} cut

We fit to the ΔE^{sig} distributions by using the double-Gaussian function, and the difference in acceptance efficiencies between data and inclusive MC sample is taken as the systematic uncertainty.The up figure shows the data fitting and the below figure shows the MC fitting,and the right table list the difference.



Decay modes	Difference (%)
$D^0 \to K^- 3\pi^+ 2\pi^-$	0.7
$D^0 \to K^- 2\pi^+ \pi^- 2\pi^0$	2.4
$D^+ \to K^- 3\pi^+ \pi^- \pi^0$	4.0

Systematic Uncertainties

- K_S^0 rejection

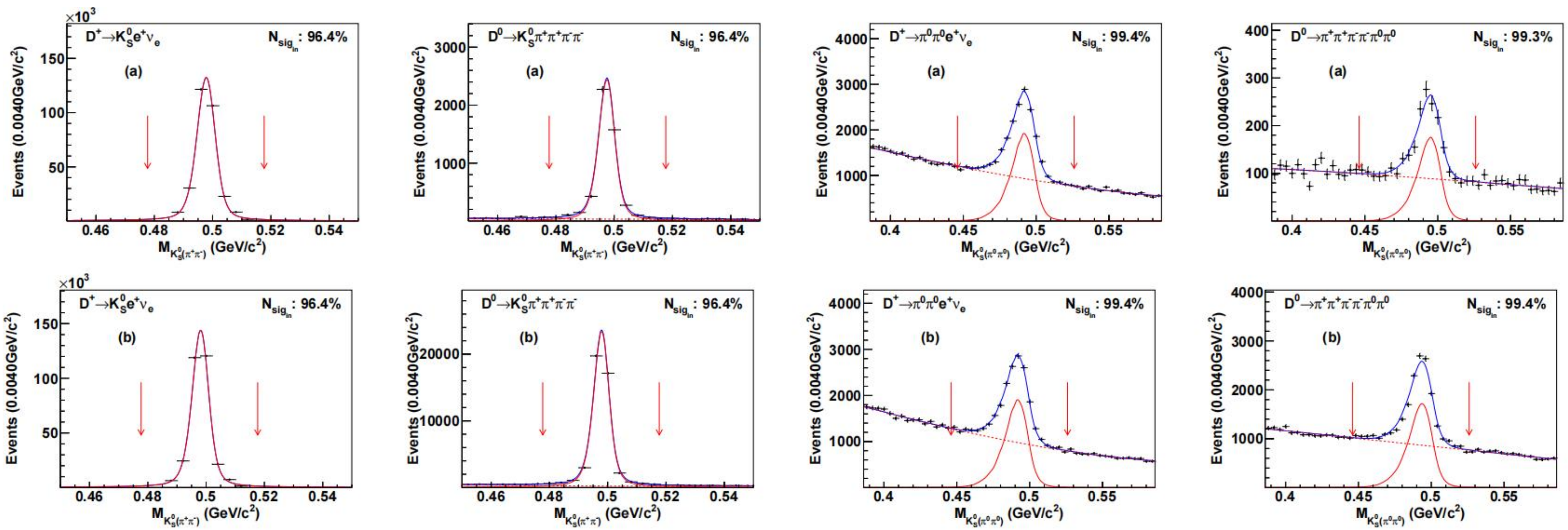
The systematic uncertainty due to the K_S^0 rejections is studied with the control sample of $D^+ \to K_S^0 e^+ V_e$, $D^+ \to 2\pi^0 e^+ V_e$, $D^0 \to K_S^0 K_S^0 2\pi^+ 2\pi^-$ and $D^0 \to 2\pi^+ 2\pi^- 2\pi^0$.

We fit the K_S^0 mass spectra by using the signal shape derived from the inclusive MC sample convolved with single-Gaussian function as signal,and using the polynomial function to describe the combinatorial background.

The acceptance efficiencies for data and MC simulation are well consistent with each other.

Systematic Uncertainties

- K_S^0 Fit



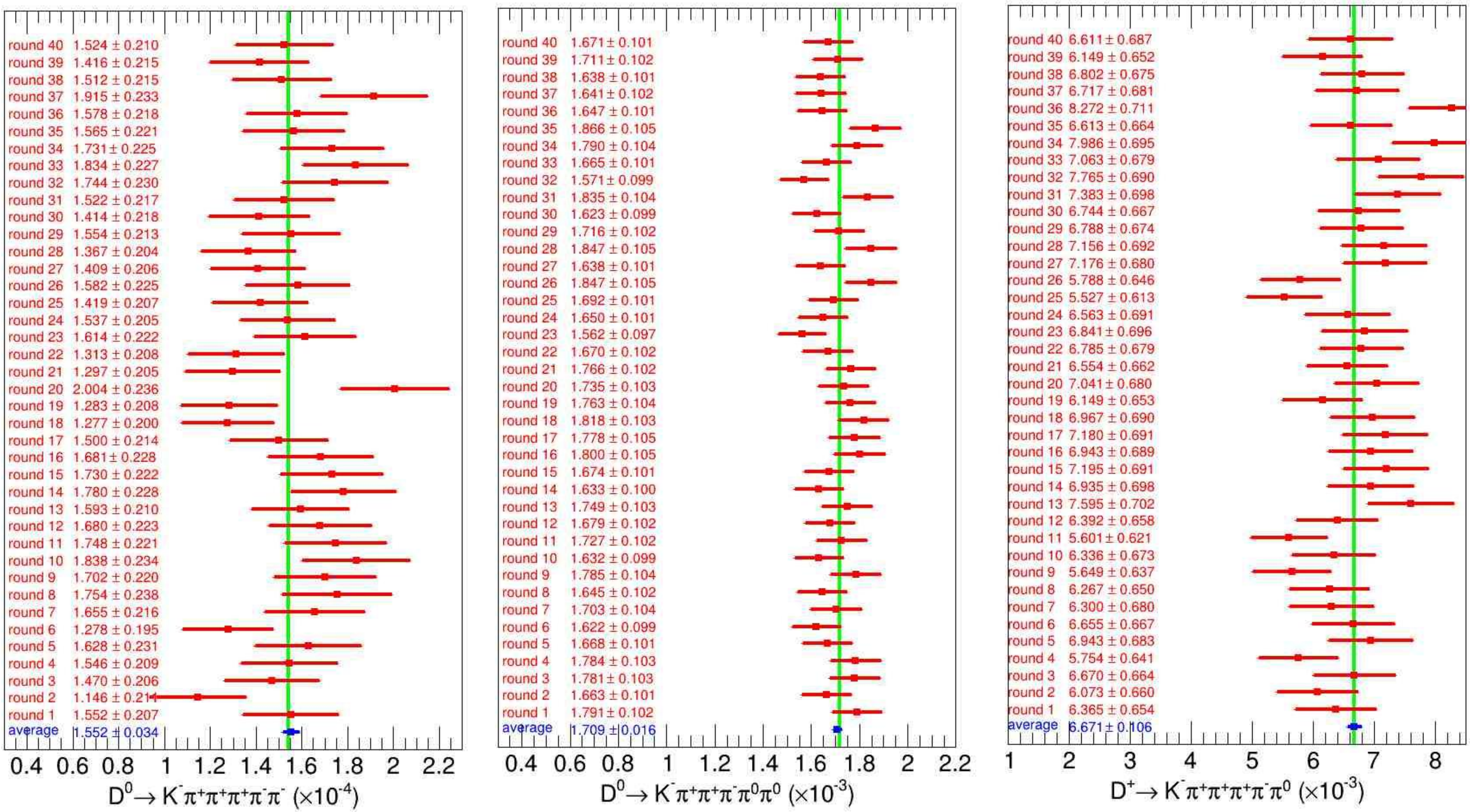
Systematic Uncertainties

- 2D Fit

Signal shape: We try to obtain new functions by changing the matching angle from 15° to 20° or 10° to obtain an alternative signal shape. The larger changes of the fitted signal yields are taken as the uncertainties.

Background shape: we modify the ARGUS endpoint from 1.8865 to 1.8863 or 1.8867 GeV/c^2. We compare the re-measured and nominal BFs, and take the larger change as the systematic uncertainties.

IO check



The up displays the difference of the BFs between the input and output in the 40×MCsample.

Summary

- By analyzing an e^+e^- annihilation data of 7.9 fb^{-1} collected at $\sqrt{s}$ =3.773 GeV with the BESIII detector:
  - improved precision:
    - $D^0 \to K^- 3\pi^+ 2\pi^-$
  - measured for the first time:
    - $D^0 \to K^- 2\pi^+ \pi^- 2\pi^0$
    - $D^+ \to K^- 3\pi^+ \pi^- \pi^0$

Over

Thank you！