First Measurement of the Absolute Branching Fraction for $\Lambda \to p\mu^{-}\bar{\nu}_{\mu}$

Shun Wang, Tao Luo

Fudan University

2020.09.01

More detailed systematical uncertainty study

Sources	Systematic uncertainty(%)
N_{tag}	0.71
4C fit	**2.68**
Cut for $m_{\bar{\Lambda}p}^{recoil}$	**10.74**
Cut for $m_{p\mu(4C)}^{sig}$	**4.03**
N_{sig}	0.67
MC statistics	0.01
Tracking for p	1.00
Tracking for μ	1.00
PID for μ	2.00
Sum	12.07

This table have been presented in light hadron meeting on July 30

Refer to the method which Patrik used in BAM-00388

$$\Delta a = |a_{main} - a_{syst}|$$

Δa: Absolute difference between the main result and the systematical test result

a_{main}: Main result

a_{syst}: Systematical test result

$$\sigma_{a,uncorr.} = \sqrt{|\sigma^2_{a,main} - \sigma^2_{a,syst}|}$$

$\sigma_{a,uncorr.}$: Uncorrelated uncertainty

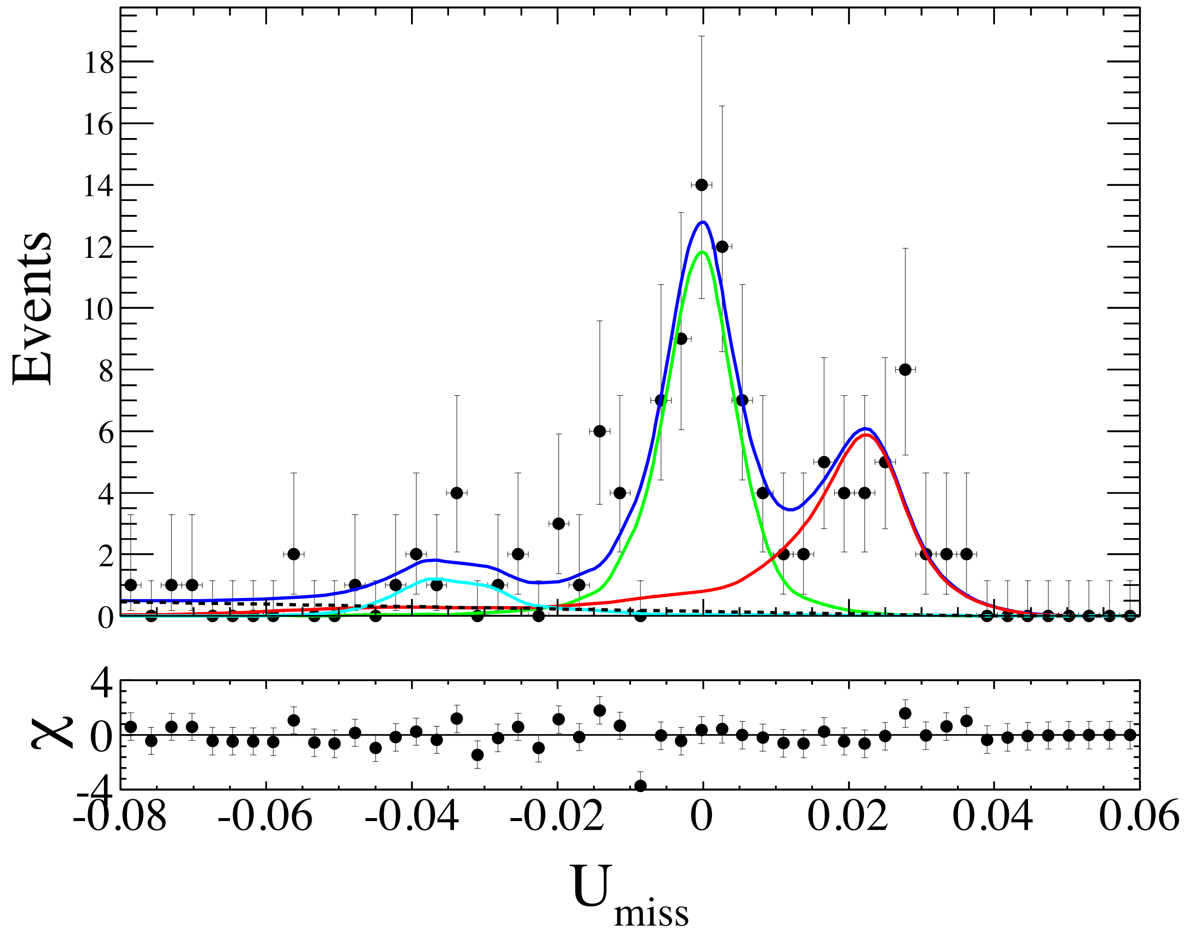
$\sigma_{a,main}$: Statistical uncertainty of main result

$\sigma_{a,syst}$: Statistical uncertainty of systematical test result

$$\zeta = \Delta a / \sigma_{a,uncorr.}$$

As a general rule of thumb, we chose to **consider $\zeta > 2$ as a threshold for when a test is significantly deviating from the main result.** Even in a sample with no systematic effects present one expects $\zeta > 2$ for one out of twenty cross checks.

Main cuts and result

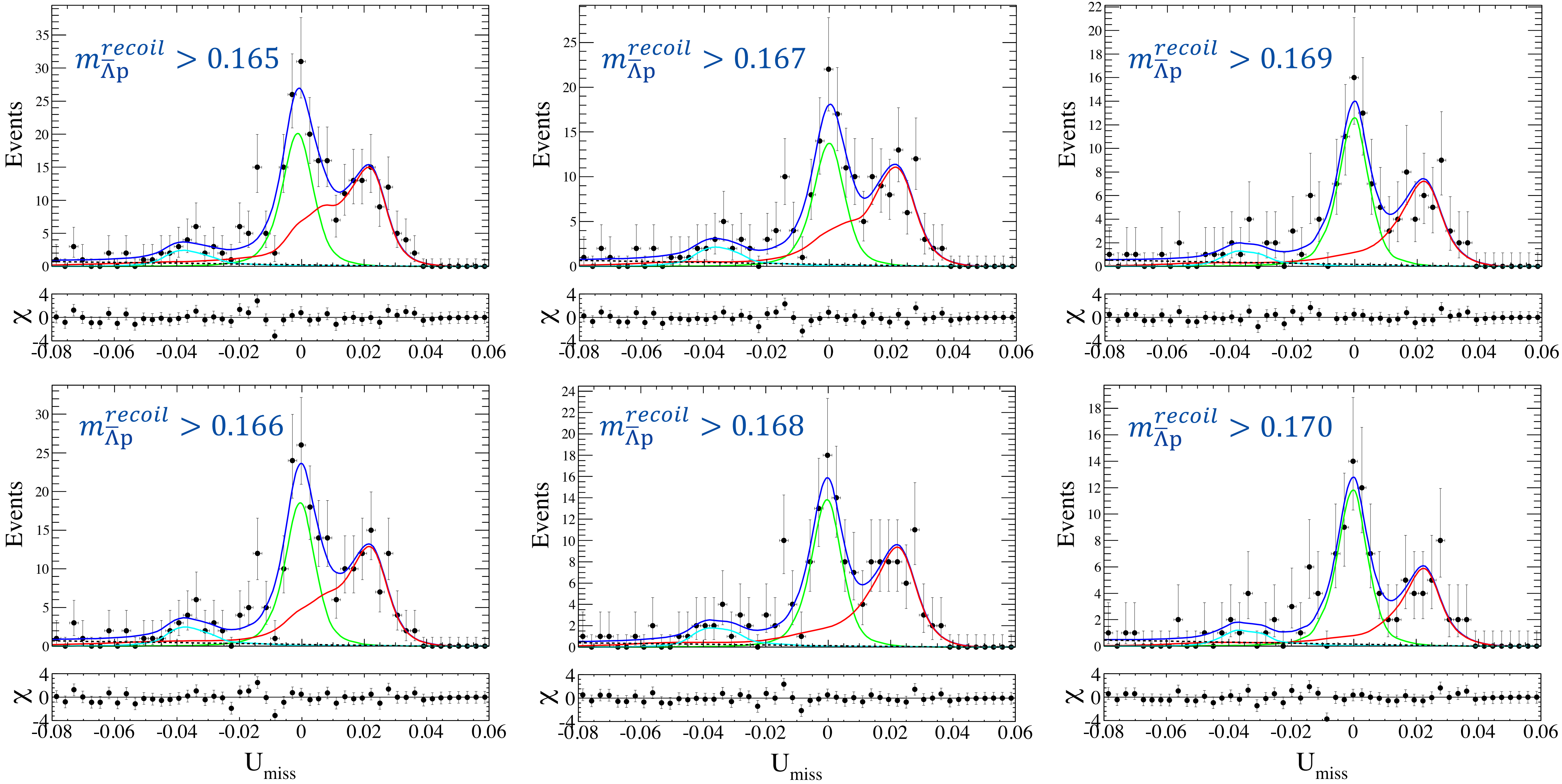


- ✓ **Signal:** MC matched shape ⊗ a Gaussian
- ✓ **Background 1:** MC shape
  from $J/\psi \to \Lambda\bar{\Lambda},\ \Lambda \to \mathrm{p}\pi^-, \bar{\Lambda} \to \bar{\mathrm{p}}\pi^+$
- ✓ **Background 2:** MC shape
  from $J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to \mathrm{p}e^-\bar{\nu}_e, \bar{\Lambda} \to \bar{\mathrm{p}}\pi^+$ +c.c.
- ✓ Other background: 1st order polynomial

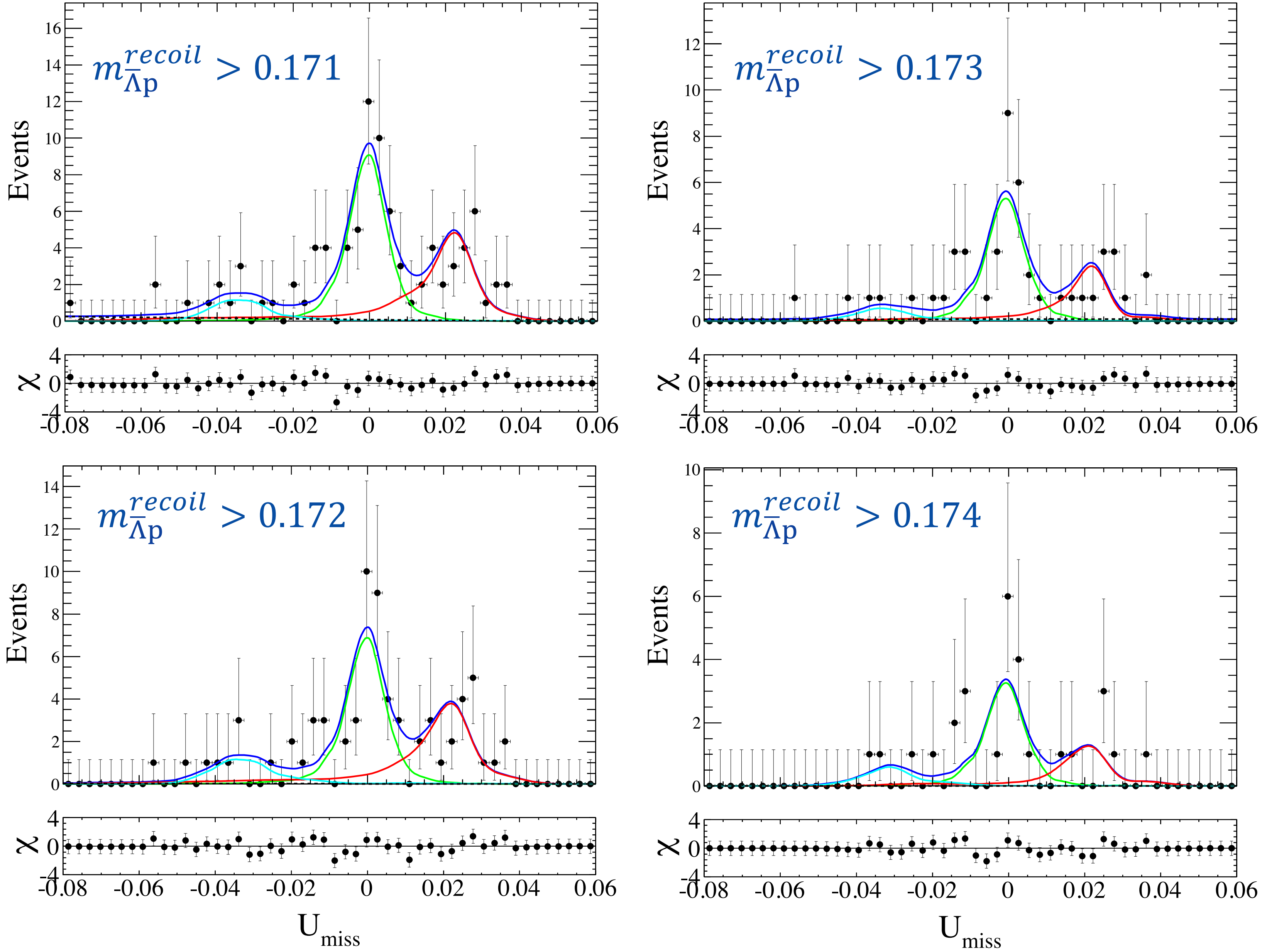
$m^{recoil}_{\bar{\Lambda}\mathrm{p}} > 0.170$ $\quad 1.075 < m^{sig}_{\mathrm{p}\mu(4C)} < 1.100$ $\quad \chi^2_{4C} > 60$

1.Systematical uncertainty test for $m_{\bar{\Lambda}\mathrm{p}}^{recoil}$ cut

DT yield in data with different $m_{\bar{\Lambda}p}^{recoil}$ cut



DT yield in data with different $m_{\bar{\Lambda}p}^{recoil}$ cut

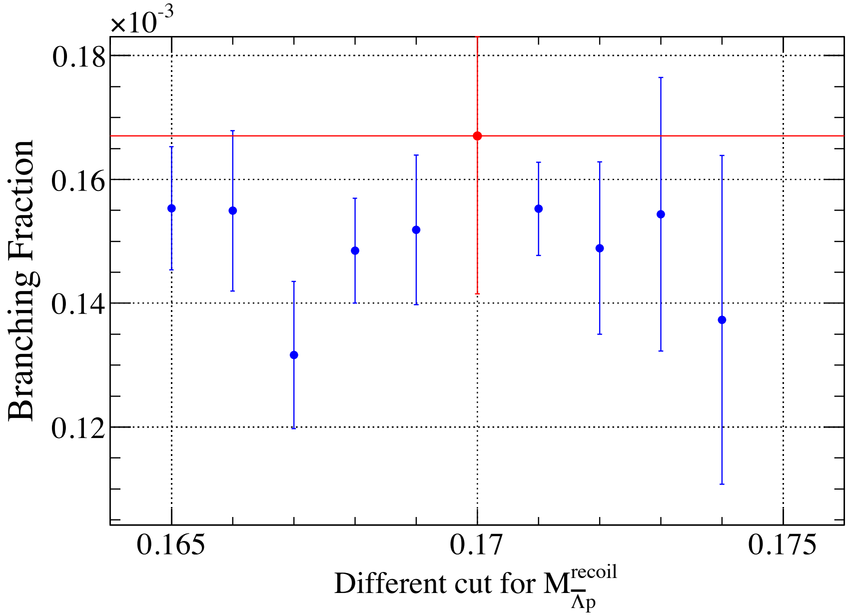


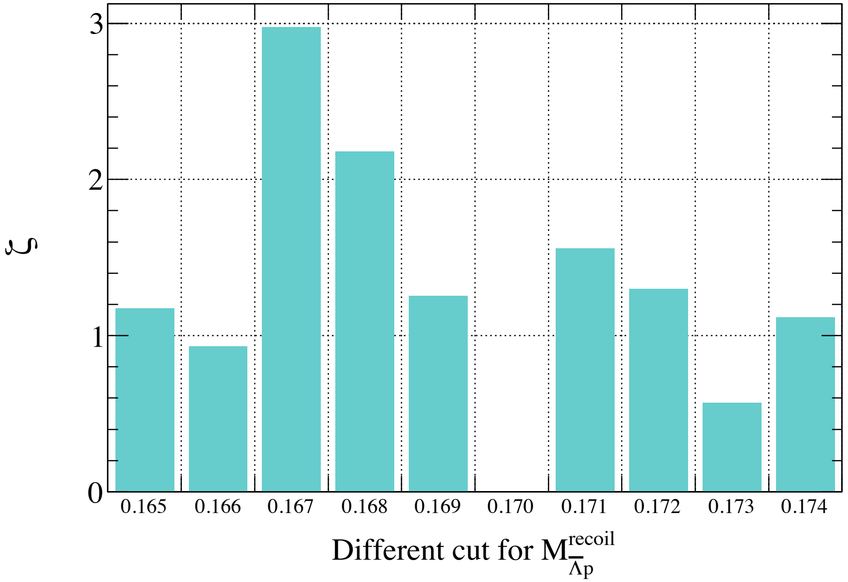
Branching fraction with different $m_{\bar{\Lambda}p}^{recoil}$ cut

Different Cut(>)	Branching Fraction	Statistical Uncertainty	Percent
0.165	1.55E-04	2.35E-05	15.13%
0.166	1.55E-04	2.20E-05	14.19%
0.167	1.32E-04	2.26E-05	17.16%
0.168	1.48E-04	2.41E-05	16.21%
0.169	1.52E-04	2.25E-05	14.81%
0.170	**1.67E-04**	**2.55E-05**	**15.28%**
0.171	1.55E-04	2.66E-05	17.14%
0.172	1.49E-04	2.91E-05	19.53%
0.173	1.54E-04	3.38E-05	21.88%
0.174	1.37E-04	3.68E-05	26.83%

Systematical uncertainty for $m_{\Lambda p}^{recoil}$ cut

After 9 tests, there are two ζ values lager than 2. However, these two points are lower than the main cut, and we did not use these samples for analysis. Therefore, **can we ignore the systematical uncertainty?**



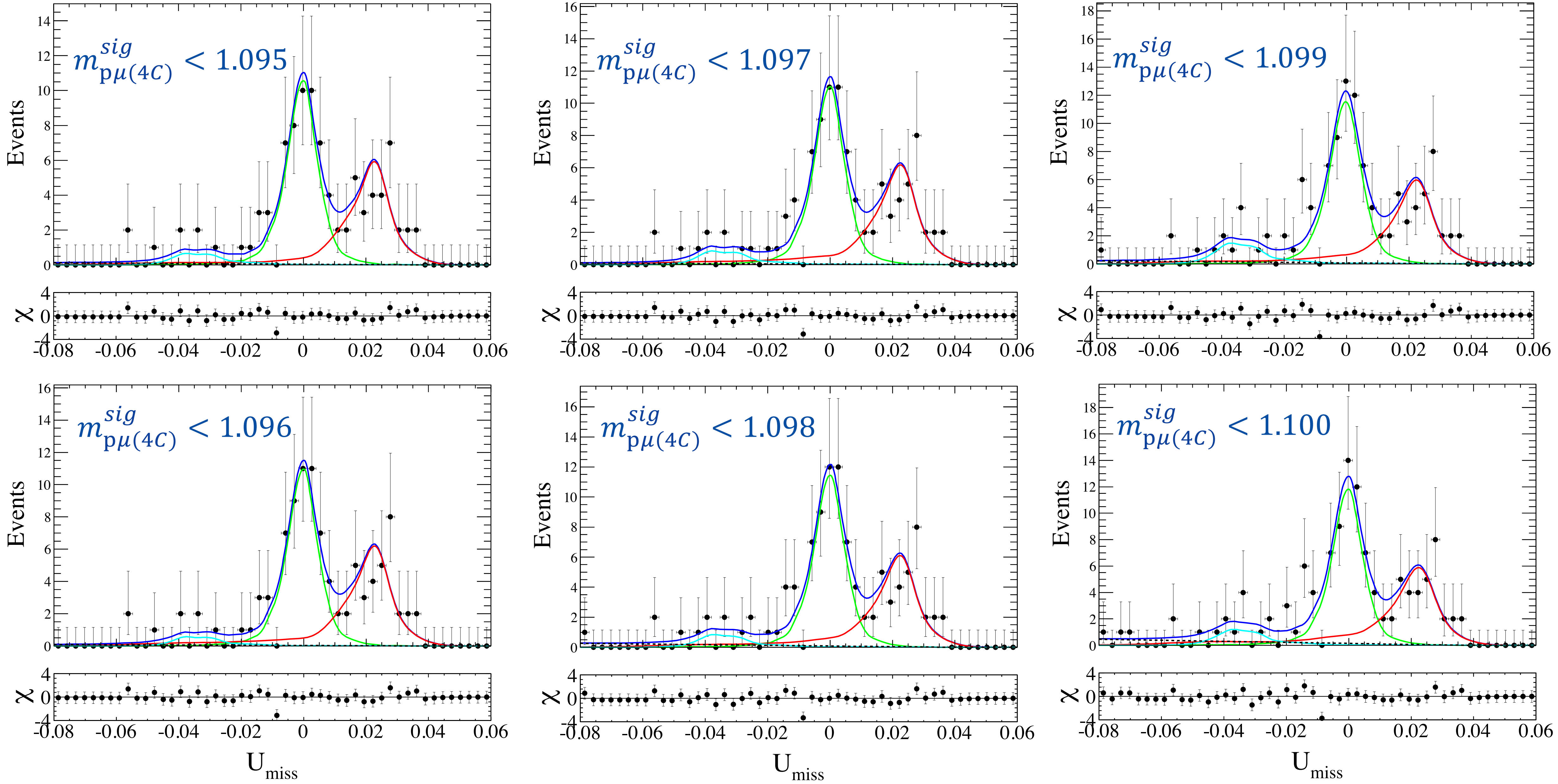


Red data point with error bar: central value with statistical uncertainty of main result.
Blue data points with error bar: central value of systematical test and uncorrelated uncertainty.
Red line: central value of main result.

The nominal cut is $m_{\Lambda p}^{recoil} > 0.170$

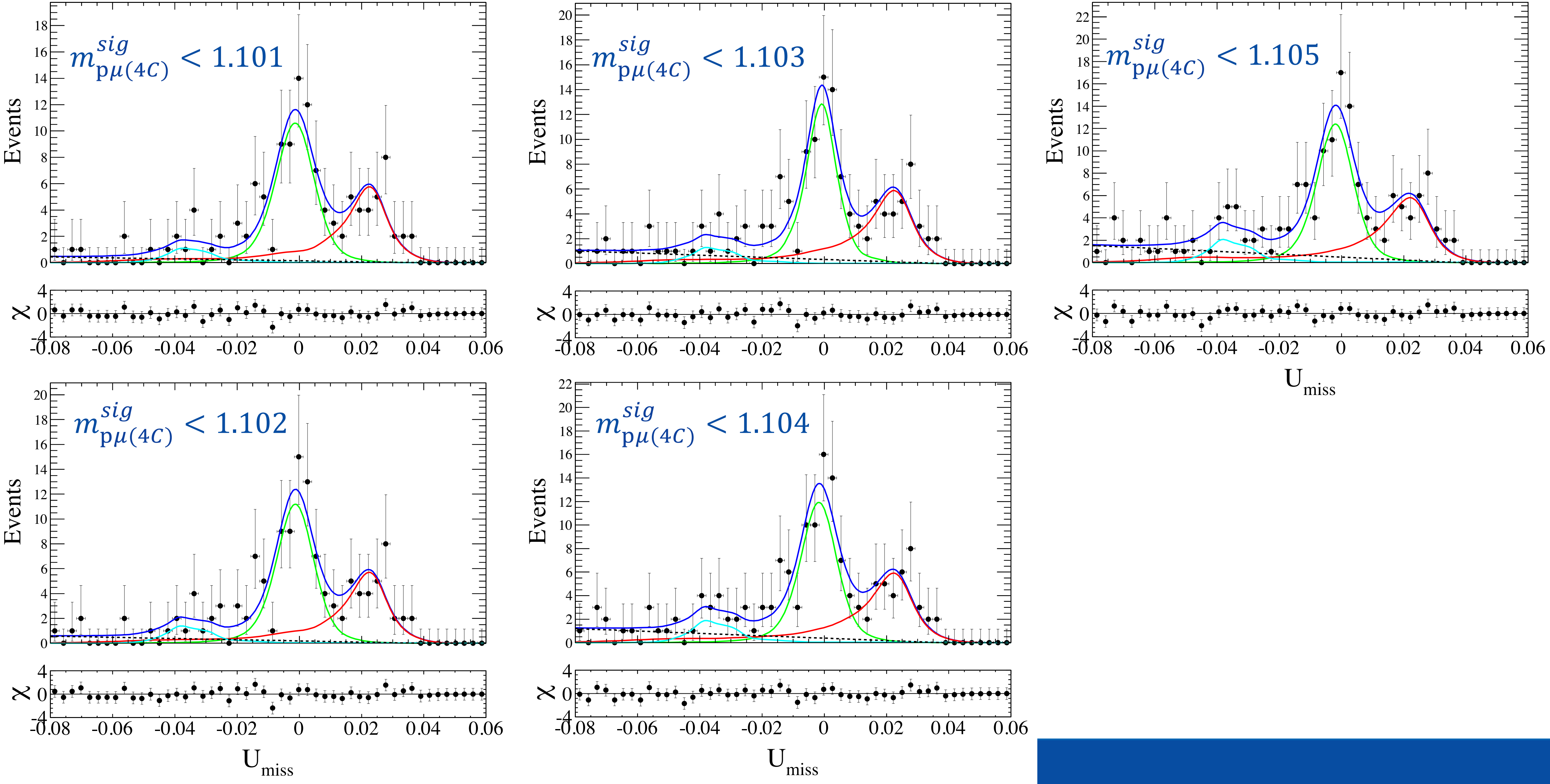
2.Systematical uncertainty test for $m_{p\mu(4C)}^{sig}$ cut

DT yield in data with different $m^{sig}_{p\mu(4C)}$ cut



复旦大学
Fudan University

DT yield in data with different $m_{p\mu(4C)}^{sig}$ cut

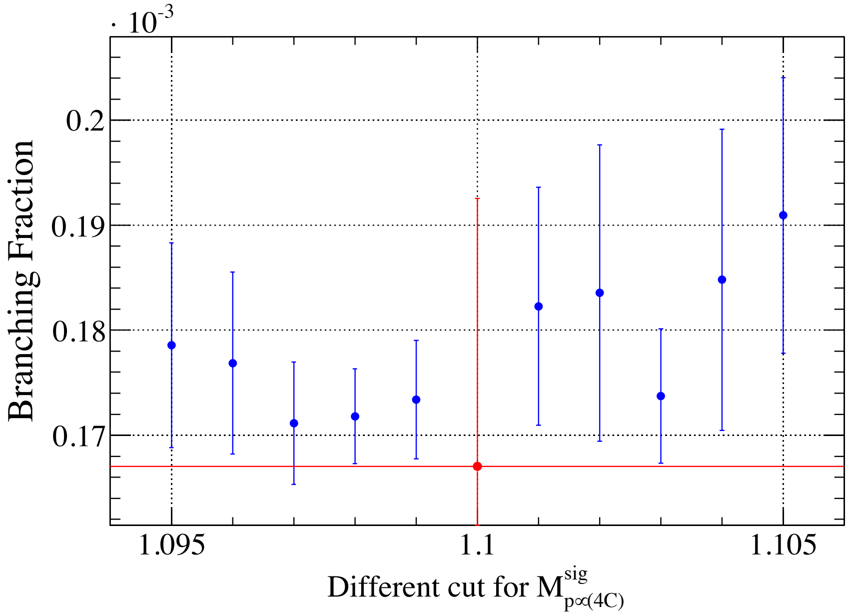


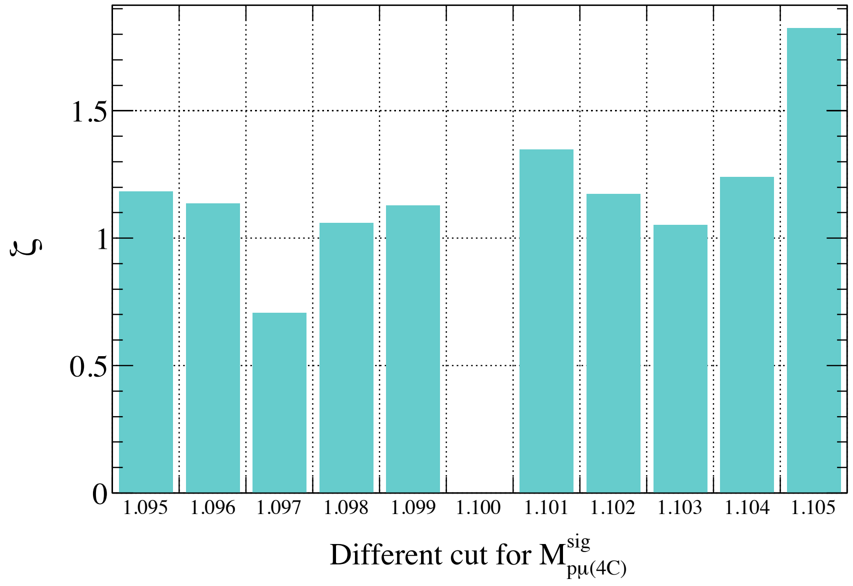
Branching fraction with different $m^{sig}_{p\mu(4C)}$ cut

Different Cut(<)	Branching Fraction	Statistical Uncertainty	Percent
1.095	1.79E-04	2.73E-05	15.30%
1.096	1.77E-04	2.70E-05	15.24%
1.097	1.71E-04	2.62E-05	15.30%
1.098	1.72E-04	2.59E-05	15.09%
1.099	1.73E-04	2.61E-05	15.08%
1.100	**1.67E-04**	**2.55E-05**	**15.28%**
1.101	1.82E-04	2.79E-05	15.32%
1.102	1.84E-04	2.92E-05	15.89%
1.103	1.74E-04	2.63E-05	15.14%
1.104	1.85E-04	2.93E-05	15.84%
1.105	1.91E-04	2.87E-05	15.03%

Systematical uncertainty for $m_{p\mu(4C)}^{sig}$ cut

After 10 tests, the values of all ζ are smaller than 2, therefore, the systematical uncertainty can be ignored.

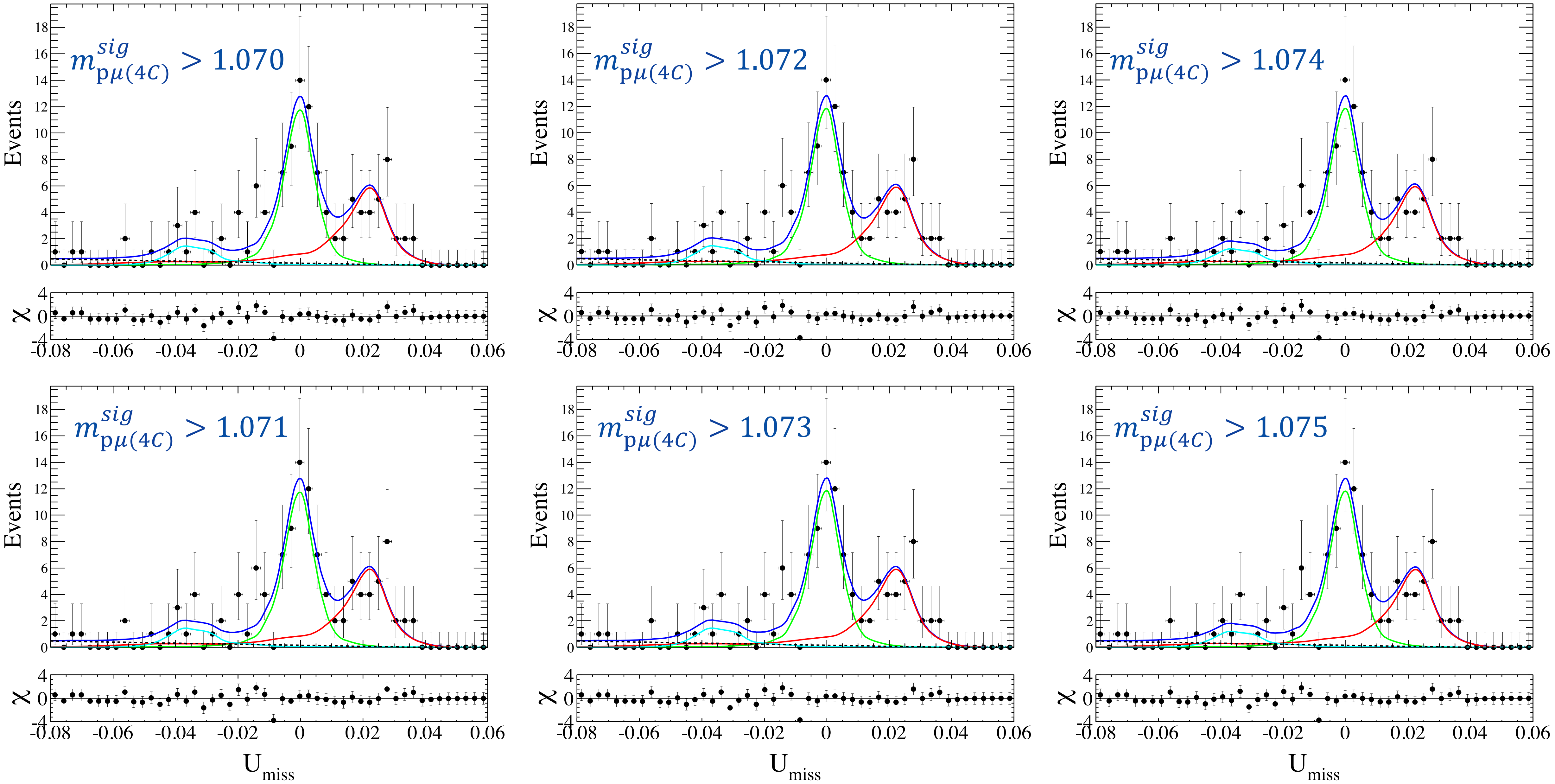




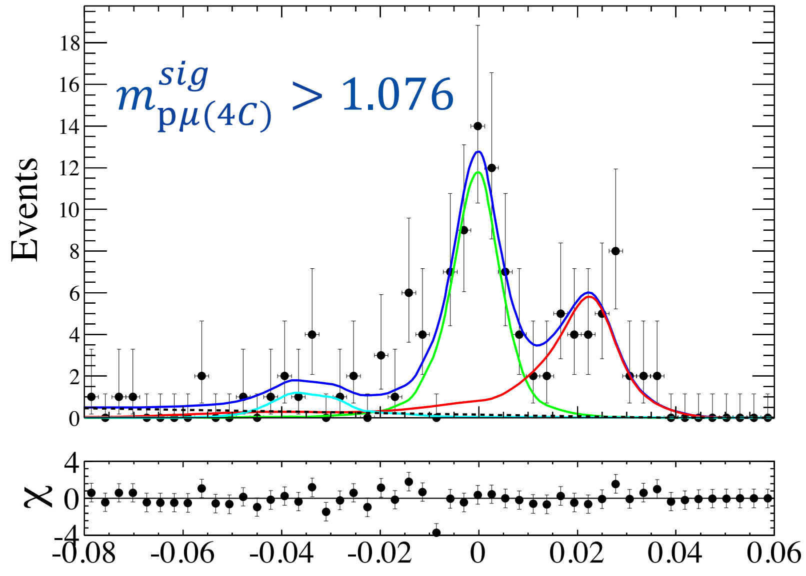
Red data point with error bar: central value with statistical uncertainty of main result.
Blue data points with error bar: central value of systematical test and uncorrelated uncertainty.
Red line: central value of main result.

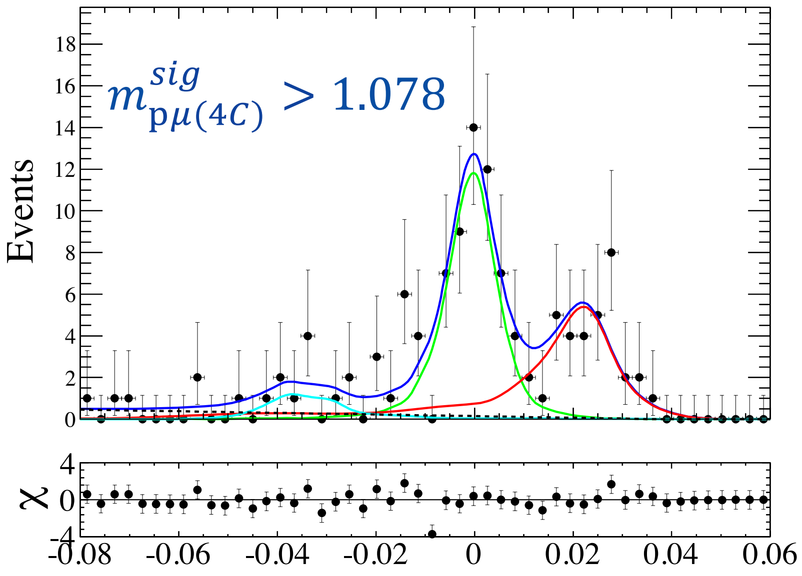
The nominal cut is $m_{p\mu(4C)}^{sig} < 1.100$

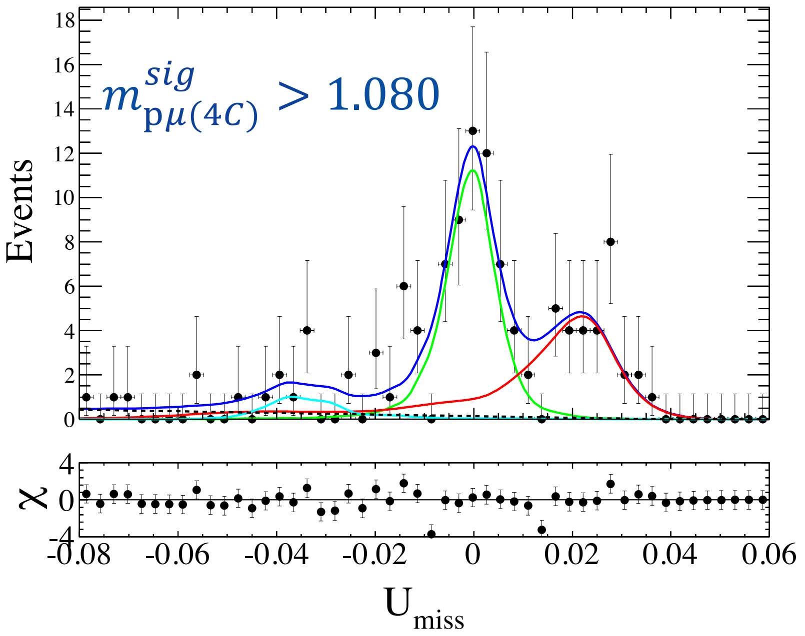
DT yield in data with different $m_{p\mu(4C)}^{sig}$ cut

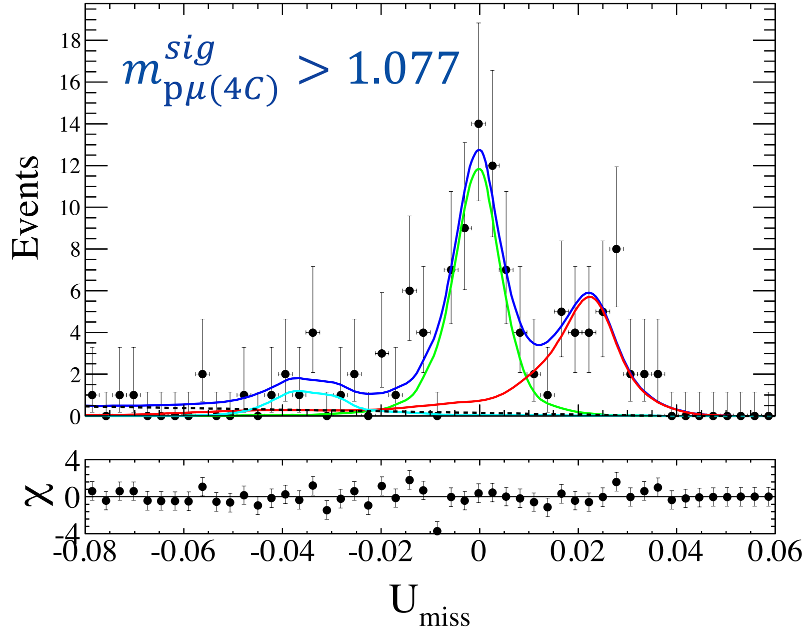


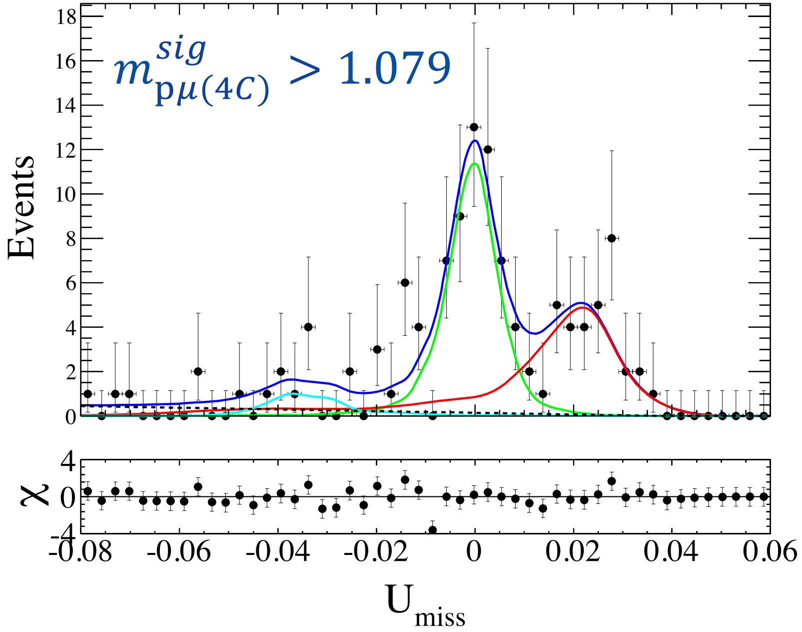
DT yield in data with different $m_{p\mu(4C)}^{sig}$ cut









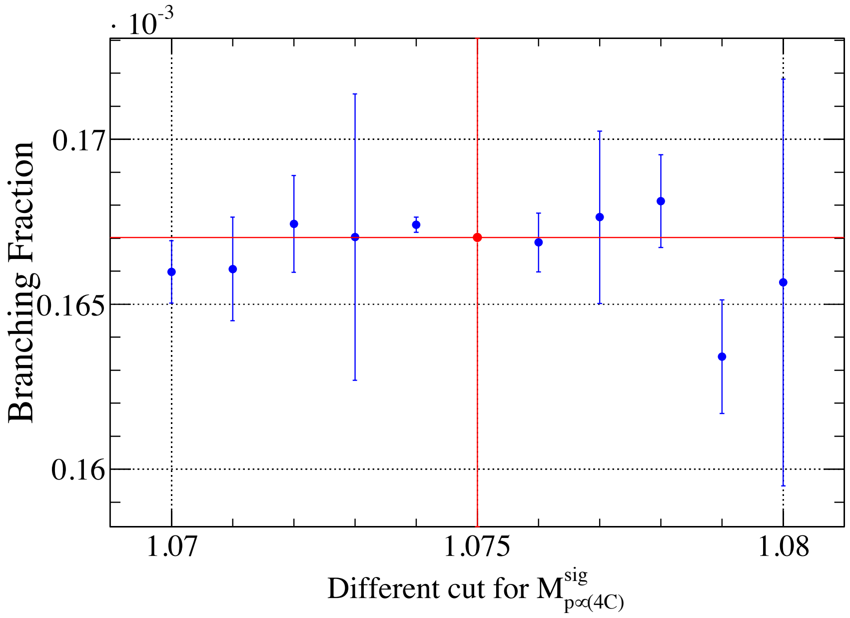


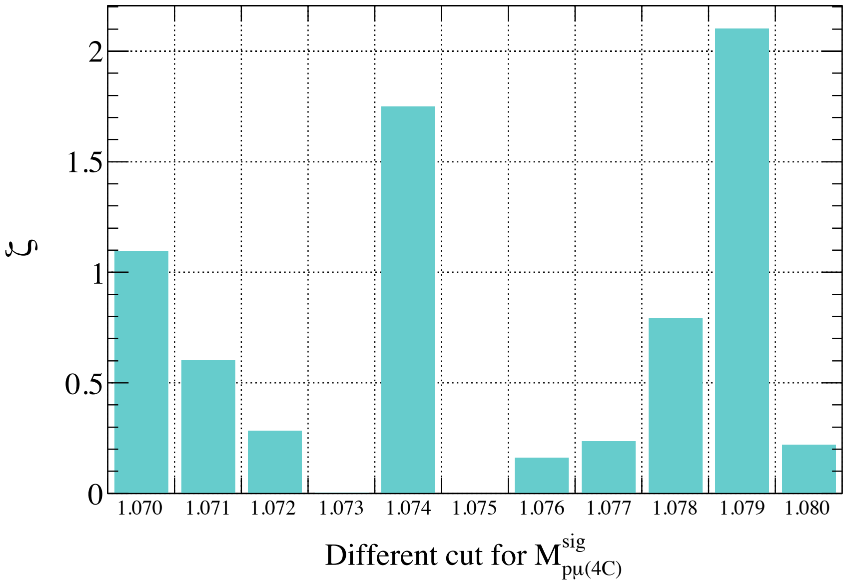
Branching fraction with different $m_{p\mu(4C)}^{sig}$ cut

Different Cut(>)	Branching Fraction	Statistical Uncertainty	Percent
1.070	1.66E-04	2.55E-05	15.39%
1.071	1.66E-04	2.56E-05	15.40%
1.072	1.67E-04	2.56E-05	15.27%
1.073	1.67E-04	2.52E-05	15.06%
1.074	1.67E-04	2.55E-05	15.25%
1.075	**1.67E-04**	**2.55E-05**	**15.28%**
1.076	1.67E-04	2.55E-05	15.29%
1.077	1.68E-04	2.54E-05	15.15%
1.078	1.68E-04	2.55E-05	15.16%
1.079	1.63E-04	2.56E-05	15.65%
1.080	1.66E-04	2.63E-05	15.85%

Systematical uncertainty for $m_{p\mu(4C)}^{sig}$ cut

After 10 tests, only the maximum value of ζ is close to 2. In addition, these results do not show a clear behavior, so we think that the systematic uncertainty can be ignored.



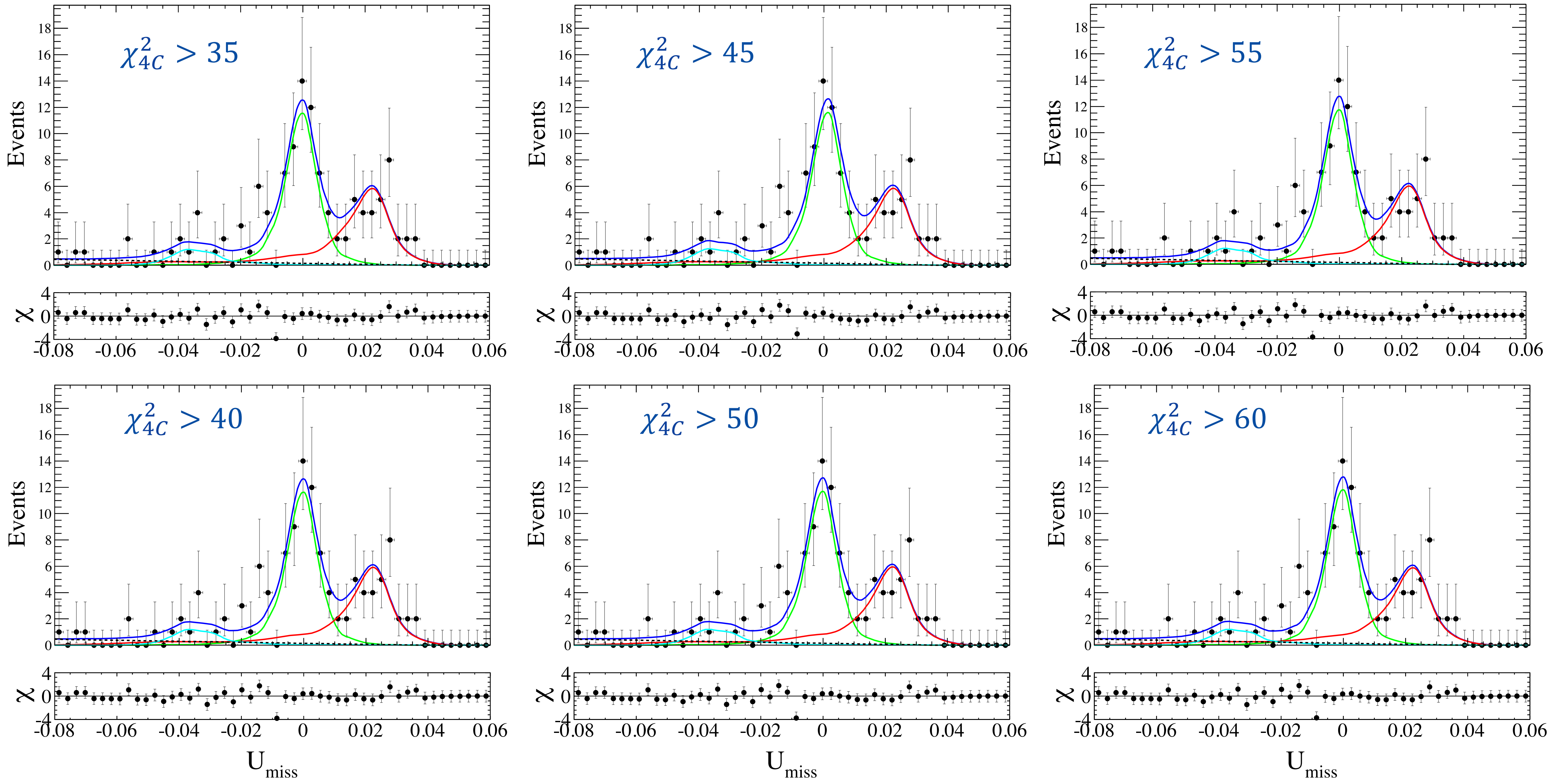


Red data point with error bar: central value with statistical uncertainty of main result.
Blue data points with error bar: central value of systematical test and uncorrelated uncertainty.
Red line: central value of main result.

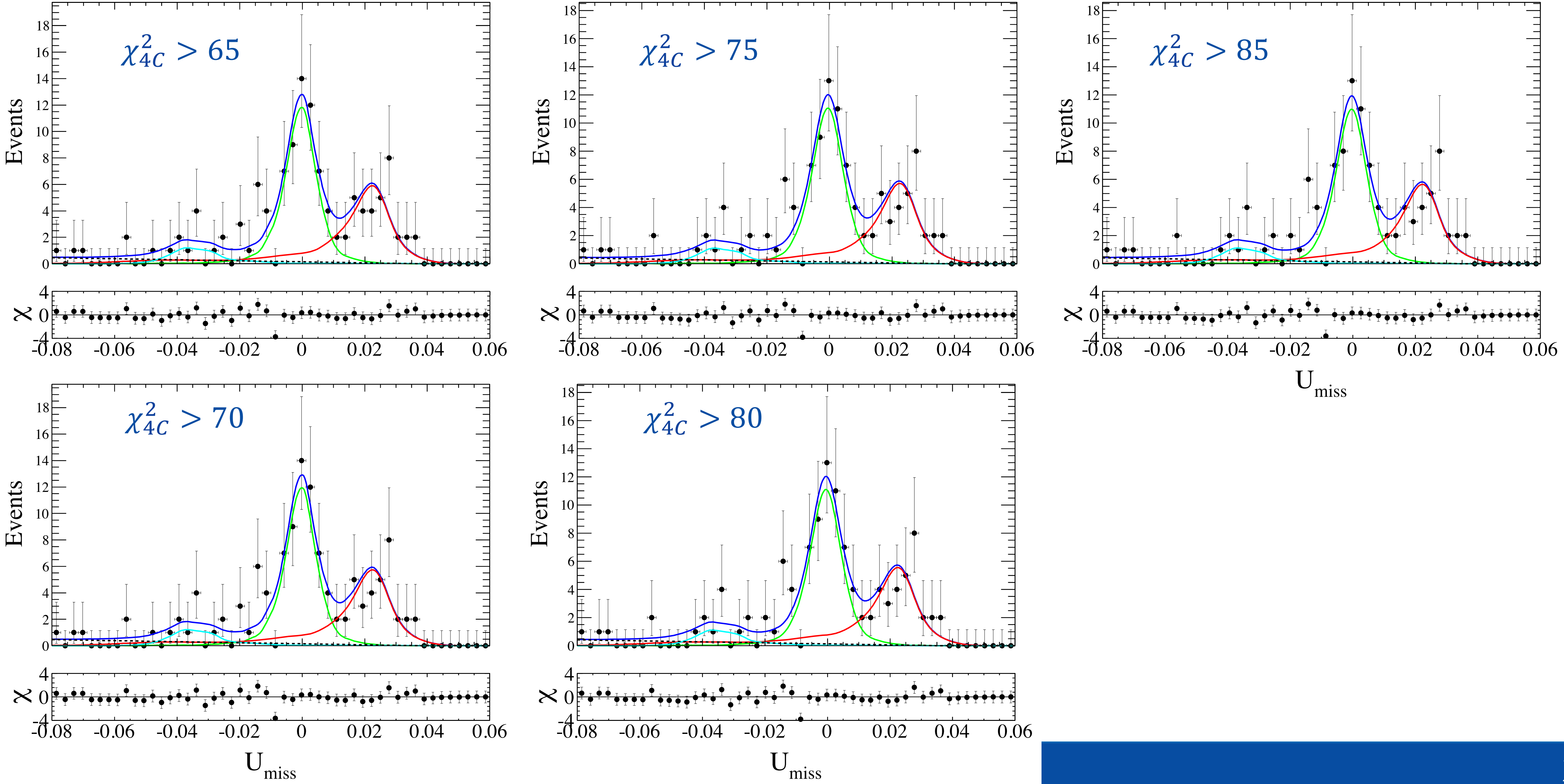
The nominal cut is $m_{p\mu(4C)}^{sig} > 1.075$

3.Systematical uncertainty test for χ^2_{4C} cut

DT yield in data with different χ^2_{4C} cut



DT yield in data with different χ^2_{4C} cut



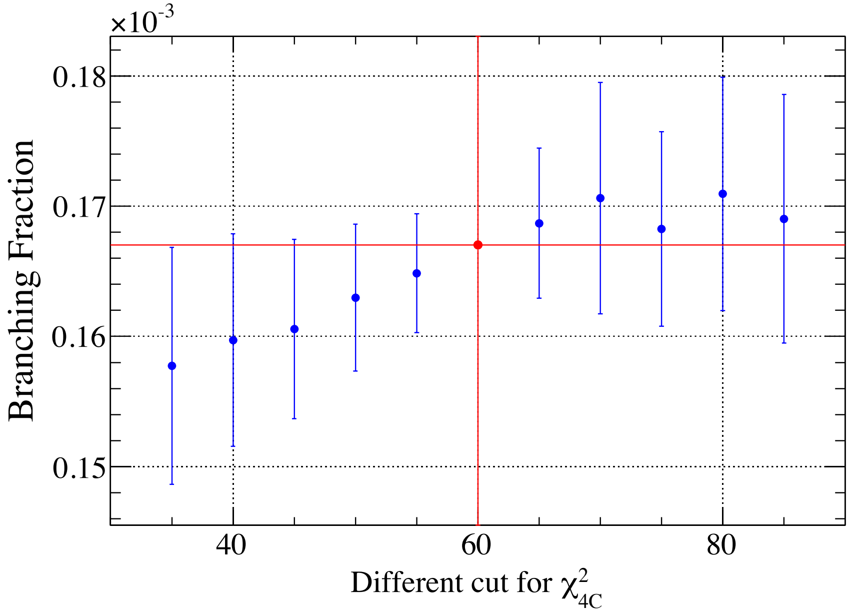
Branching fraction with different χ^2_{4C} cut

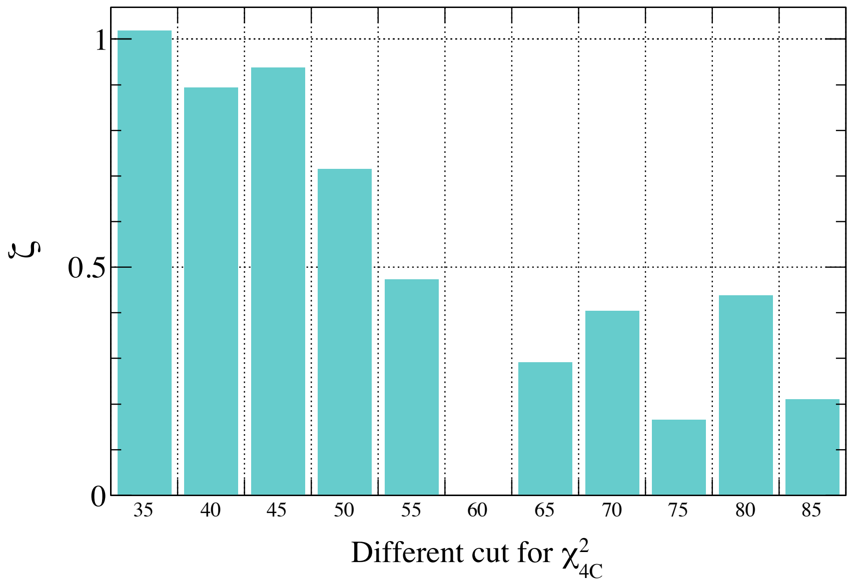
Different Cut(>)	Branching Fraction	Statistical Uncertainty	Percent
35	1.58E-04	2.38E-05	15.12%
40	1.60E-04	2.42E-05	15.14%
45	1.61E-04	2.46E-05	15.31%
50	1.63E-04	2.49E-05	15.27%
55	1.65E-04	2.51E-05	15.23%
60	**1.67E-04**	**2.55E-05**	**15.28%**
65	1.69E-04	2.62E-05	15.51%
70	1.71E-04	2.70E-05	15.84%
75	1.68E-04	2.66E-05	15.81%
80	1.71E-04	2.71E-05	15.83%
85	1.69E-04	2.72E-05	16.12%

Fudan University

Systematical uncertainty for χ^2_{4C} cut

After 10 tests, the values of all ζ are smaller than 2, therefore, the systematical uncertainty can be ignored.





Red data point with error bar: central value with statistical uncertainty of main result.
Blue data points with error bar: central value of systematical test and uncorrelated uncertainty.
Red line: central value of main result.

The nominal cut is $\chi^2_{4C} > 60$

Summary

Sources	Systematic uncertainty(%)
N_{tag}	0.71
~~4C fit~~	~~2.68~~
~~Cut for $m_{\Lambda p}^{recoil}$~~	~~10.74~~ ???
~~Cut for $m_{p\mu(4C)}^{sig}$~~	~~4.03~~
N_{sig}	0.67
MC statistics	0.01
Tracking for p	1.00
Tracking for μ	1.00
PID for μ	2.00
Sum	??

1. The systematical uncertainty from cut for $m_{p\mu(4C)}^{sig}$ and χ_{4C}^2 can be ignored.

2. As for cut for $m_{\Lambda p}^{recoil}$, can we ignore the systematical uncertainty from this? Other suggestions?

Backup

Some screenshots from Patrik's memo(BAM-00388)

11.2.1 Significant deviations of correlated samples

For each systematical test the maximum log-likelihood method is used to obtain the fitted parameters and their fit uncertainties. Suppose that for a given parameter a the main result is $a_{\text{main}} \pm \sigma_{a,\text{main}}$ and for a certain systematic test the fit result gives $a_{\text{syst}} \pm \sigma_{a,\text{syst}}$, and we want to know if the systematical test result significantly deviates from the main result. The first step is to compare their absolute difference, $\Delta a = |a_{\text{main}} - a_{\text{syst}}|$. To determine if Δa is a significant or acceptable deviation we also need to compare Δa to what we statistically expect the uncertainty of the difference to be. If the data sets of the systematic and main results are similar or even the same the data samples are highly correlated. This means that it is not possible to use the fit uncertainties of the main result to compare with the systematic test result. Instead the uncorrelated uncertainty has to be calculated. It is calculated as $\sigma_{a,\text{uncorr.}} = \sqrt{|\sigma^2_{a,\text{main}} - \sigma^2_{a,\text{syst}}|}$. From this the observable $\zeta = \Delta a / \sigma_{a,\text{uncorr.}}$ can be obtained. ζ gives the significant difference between the systematic test and main result. Thus, a value for ζ close to 0 shows that there is good agreement between the two data sets, while large ζ points to inconsistencies and an underlying systematic source.

Oftentimes it is not enough to perform a single systematic test for a given observable. As an example: for the χ^2_{4C} cross check, nine different χ^2_{4C} values were considered. This allows for better understanding of the systematic behavior; perhaps there are trending deviations indicative of an underlying systematic source? What constitutes as a significant deviation has to be determined on a case-by-case basis. It depends e.g. if the varied parameter shows a trending or fluctuating behavior. As a general rule of thumb in this analysis we chose to consider $\zeta > 2$ as a threshold for when a test is significantly deviating from the main result. Even in a sample with no systematic effects present one expects $\zeta > 2$ for one out of twenty cross checks.

Some screenshots from Patrik's memo(BAM-00388)

(C) **Ξ mass window selection** The Ξ mass window selection was also tested where $|m_{\Xi} - m(\Lambda\pi)|$ was varied from 2 to 20 MeV. Here $\alpha_{J/\psi}, \Delta\Phi, \alpha_{\Lambda}, \alpha_{\bar{\Lambda}}, \phi$ are found to have instances of $\zeta > 2$. For $\Delta\Phi$, $\alpha_{\bar{\Lambda}}$ and ϕ these are close to 2 and all occur above the main selection mass window, determined from the Figure-of-Merit. In addition these observables do not show a clear behavior and are therefore not considered to contain a systematic effect. Only for $\alpha_{J/\psi}$ and α_{Λ} there are significant effects for

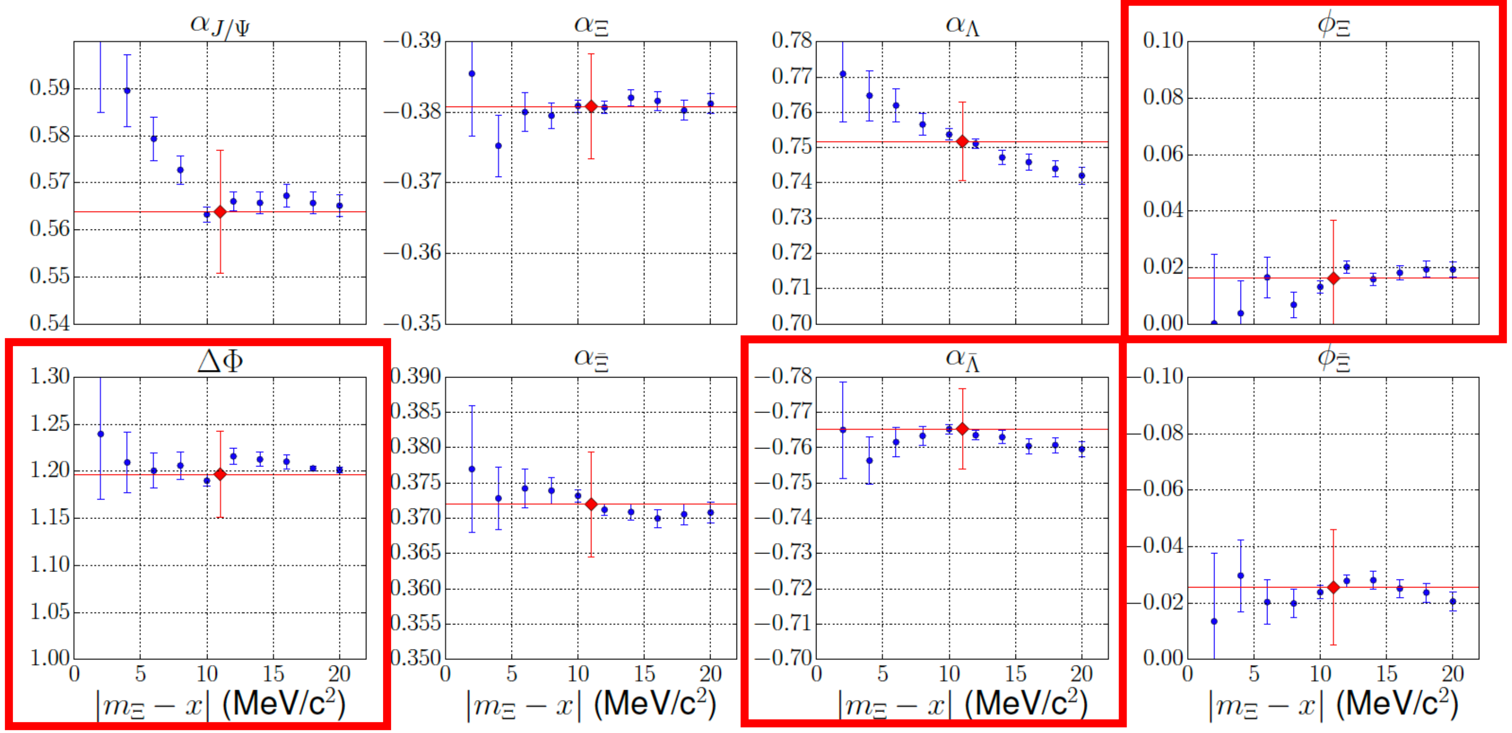


Figure 24: Parameter values as function of $|m_{\Xi} - m(\Lambda\pi)|$. Red diamond data point with error bar gives central value with fit uncertainty of main result. Blue data points with error bar give central value of systematic test and uncorrelated uncertainty. Red line gives central value of main result.

Some screenshots from Patrik's memo(BAM-00388)

(C) **Ξ mass window selection** The Ξ mass window selection was also tested where $|m_\Xi - m(\Lambda\pi)|$ was varied from 2 to 20 MeV. Here $\alpha_{J/\psi}, \Delta\Phi, \alpha_\Lambda, \alpha_{\bar{\Lambda}}, \phi$ are found to have instances of $\zeta > 2$. For $\Delta\Phi$, $\alpha_{\bar{\Lambda}}$ and ϕ these are close to 2 and all occur above the main selection mass window, determined from the Figure-of-Merit. In addition these observables do not show a clear behavior and are therefore not considered to contain a systematic effect. Only for $\alpha_{J/\psi}$ and α_Λ there are significant effects for

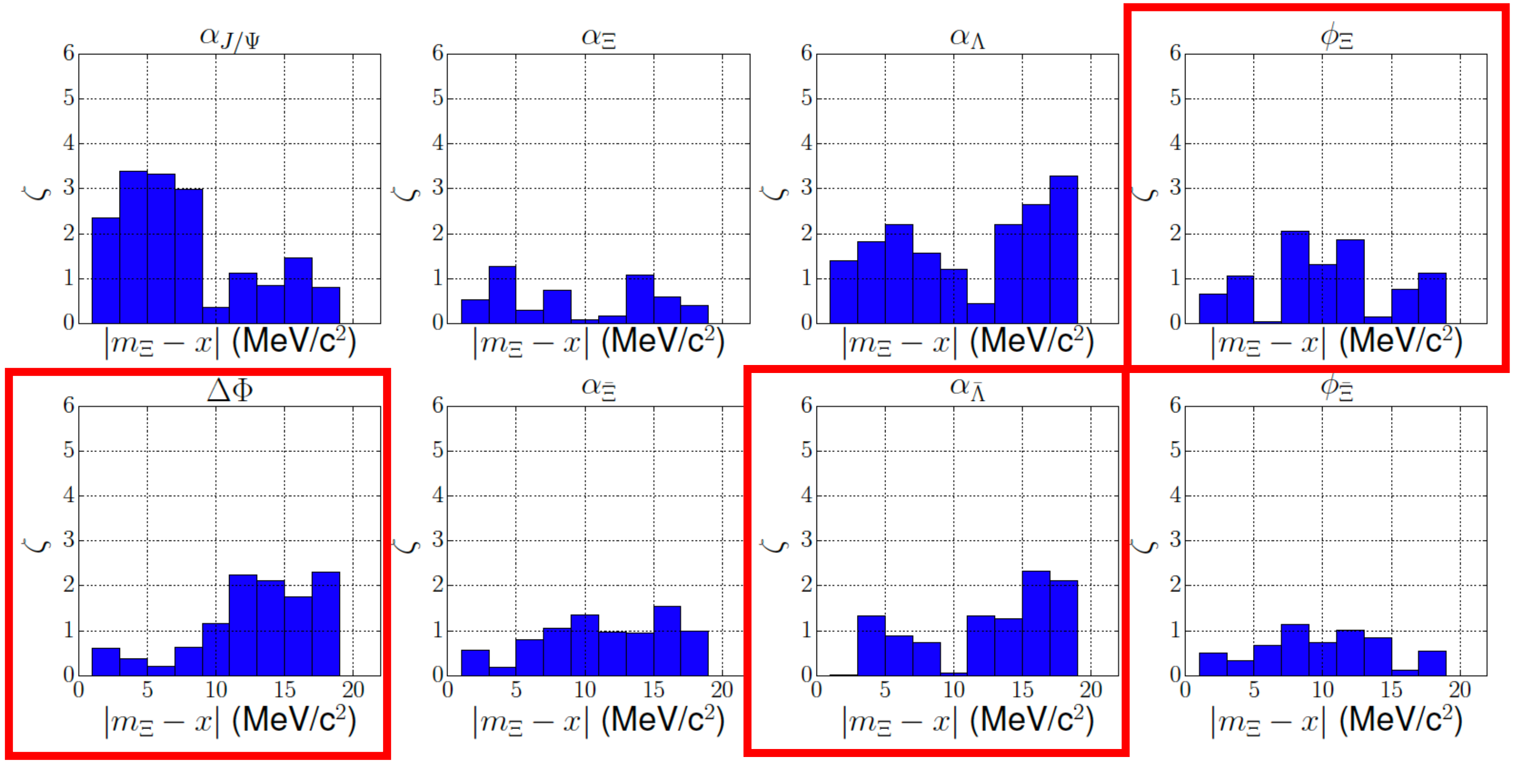
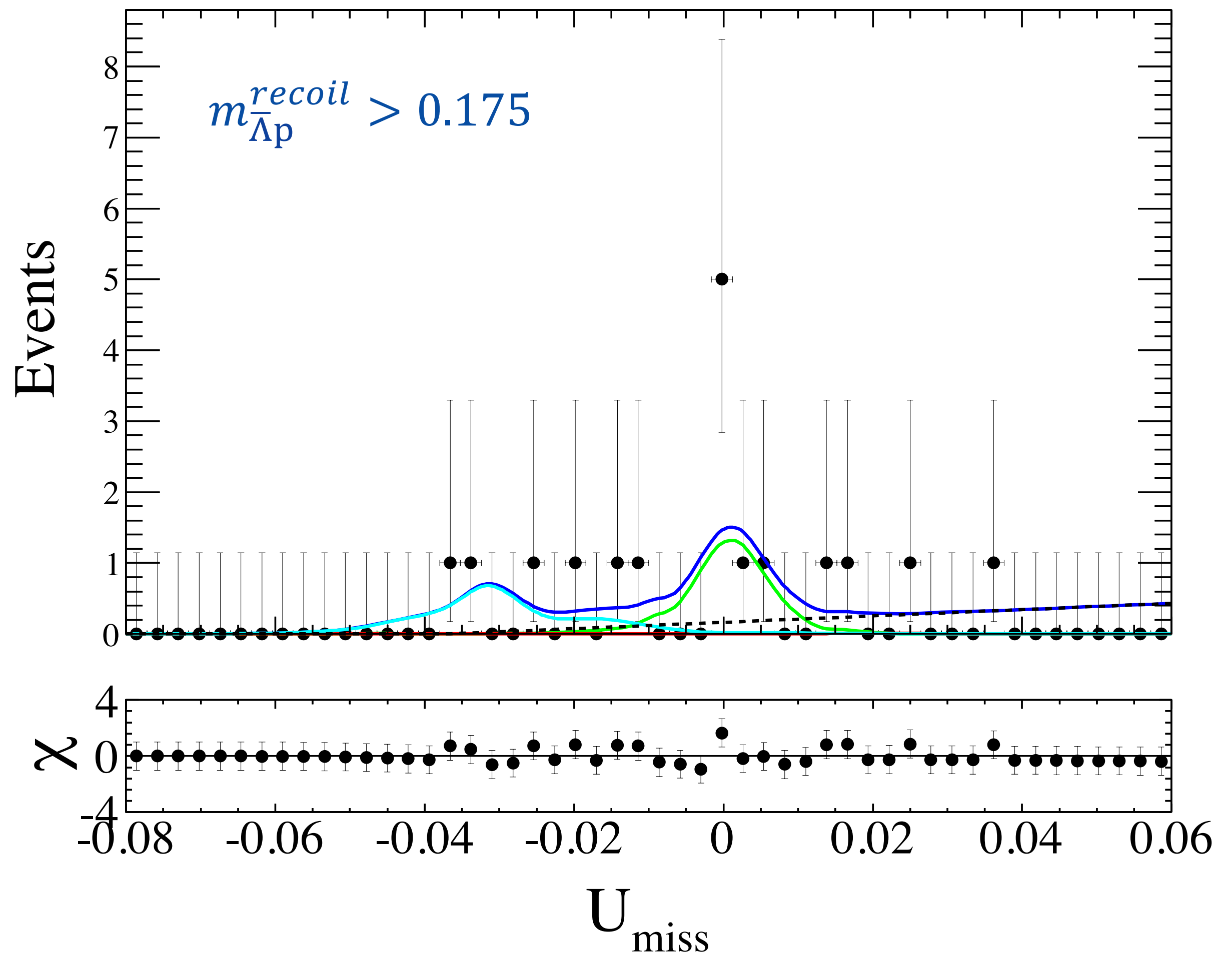


Figure 25: Significance ζ as function of $|m_\Xi - m(\Lambda\pi)|$.

DT yield in data with different $m_{\Lambda p}^{recoil}$ cut



Background analysis

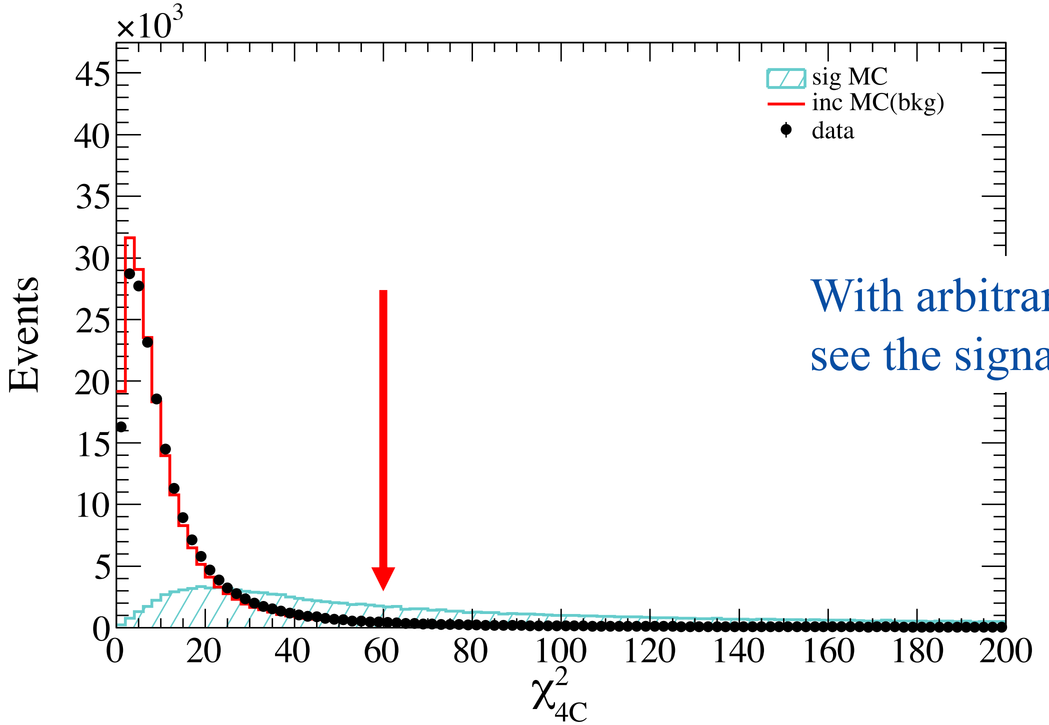
Dominant background $J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$

➢ Reconstruction of Λ

- ✓ Vertex and Second Vertex Fit for Λ based on $p\pi^-$ hypothesis
- ✓ Vertex/second vertex fit: $\chi^2 < 100$, $(Decay\ length\ /\ \sigma) > 2$

➢ 4C kinematic fit

- ✓ A 4C kinematic fit is performed to the two virtual particles (Λ and $\bar{\Lambda}$) hypothesis
- ✓ $\chi^2_{4C} > 60$



With arbitrary scale to see the signal clearly

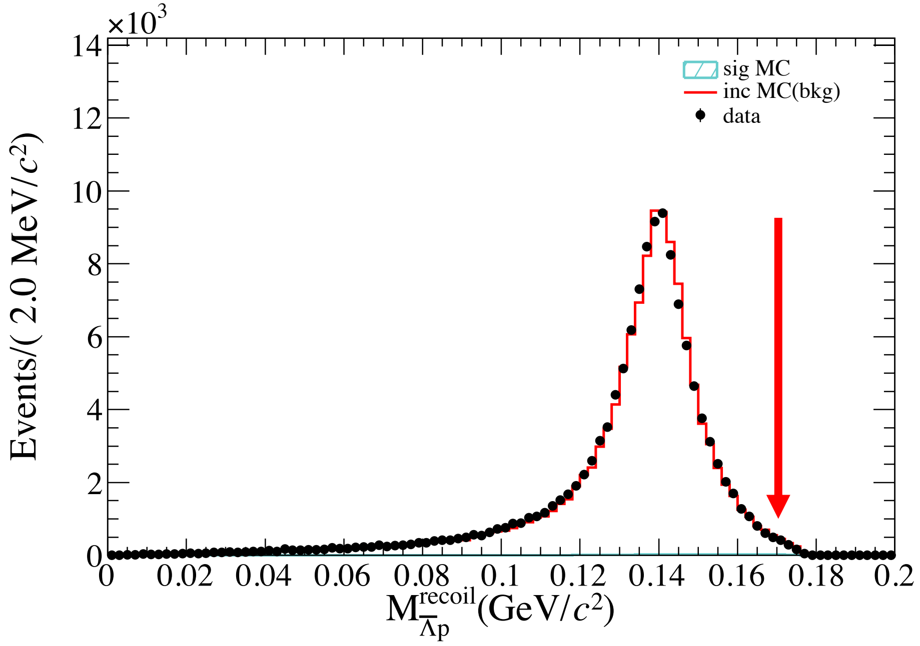
Background analysis

Dominant background $J/\psi \rightarrow \Lambda\bar{\Lambda}, \Lambda \rightarrow p\pi^-, \bar{\Lambda} \rightarrow \bar{p}\pi^+$

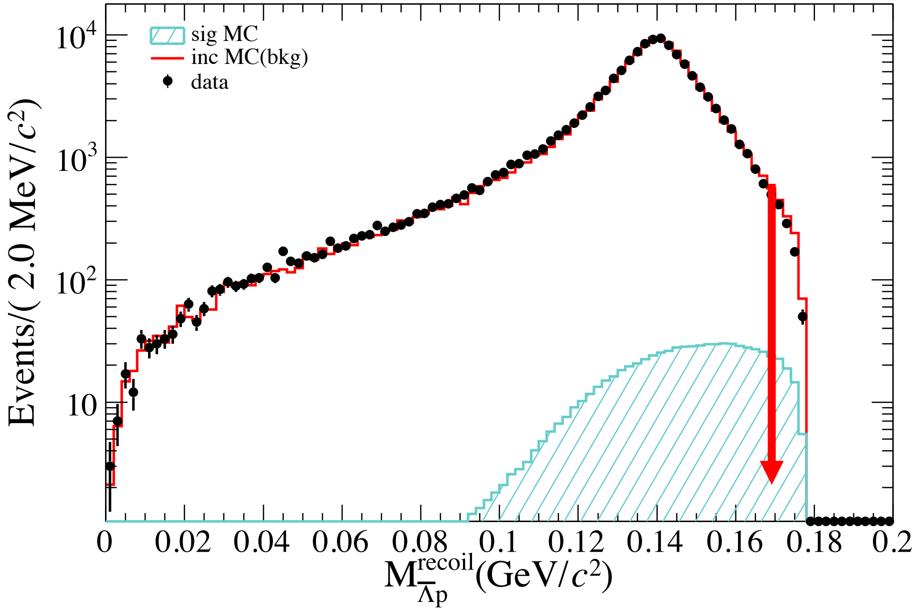
➢ **Recoiling mass of $\bar{\Lambda}$p**

✓ For this background, recoiling mass of $\bar{\Lambda}$p is expected to the value of the invariant mass of π

✓ $m_{\bar{\Lambda}p}^{recoil} > 0.17\ (GeV/c^2)$



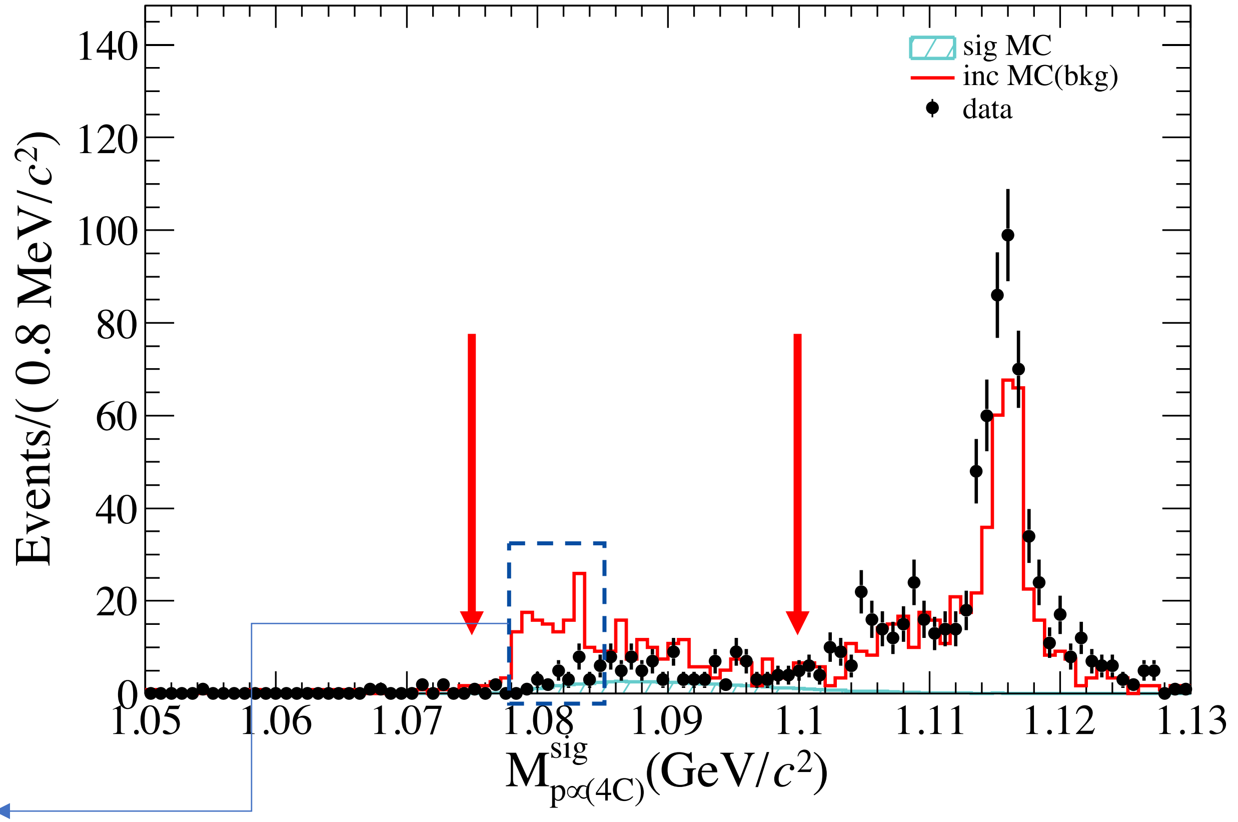
logarithmic



Background analysis

Dominant background $J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$

- **Mass of $p\mu$ after 4C kinematic fit**
  - ✓ For this background, a Λ can be reconstructed based on pπ⁻ hypothesis
  - ✓ $1.075 < m^{sig}_{p\mu(4C)} < 1.1\ (GeV/c^2)$



decay tree	decay final state	iDcyTr	nEtr
$J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to \pi^- p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^- p\bar{p}$	0	155
$J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to \pi^- p, \bar{\Lambda} \to e^+\nu_e\bar{p}$	$e^+\nu_e\pi^- p\bar{p}$	1	1