Precise Measurement of Charmed Meson Masses at BESIII

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On behalf of BESIII Collaboration

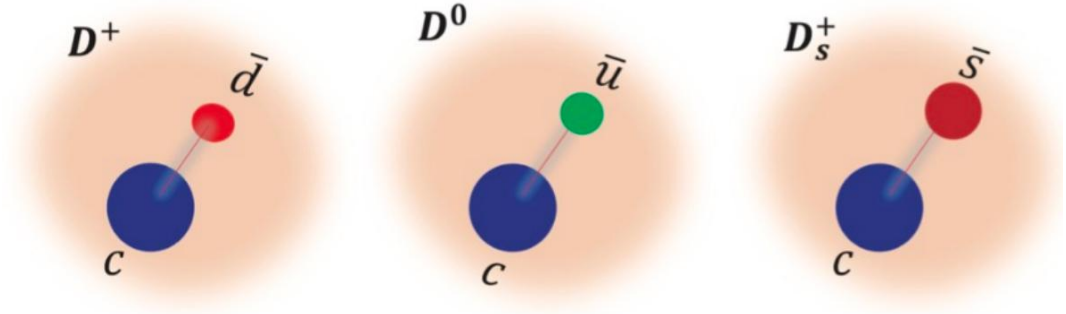
Oct. 18, 2026 @ 粲强子物理研讨会，成都理工大学

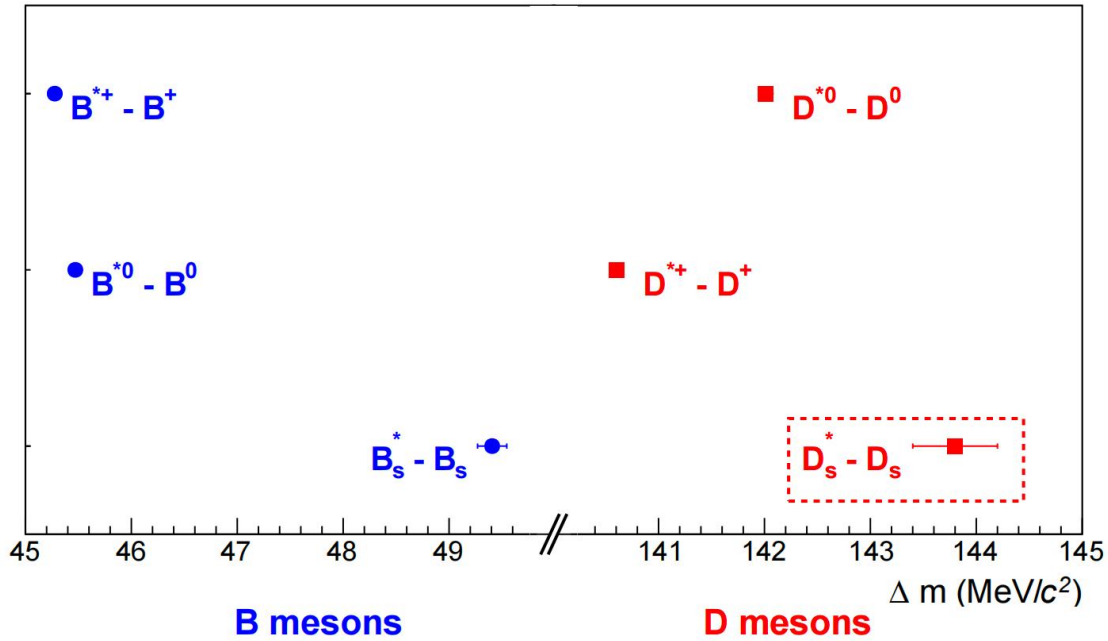
Outline

1. Motivation
2. Strategy
3. Fit model
4. π^0 Correction
5. Systematic Uncertainty
6. Results
7. Discussion
8. Summary

Motivation

- The precision of the current PDG value at $M(D_s^{*+}) - M(D_s^{+}) = 143.8 \pm 0.4$ MeV (which is predicted to be 143.77 ± 0.15 MeV[1]) is almost two orders of magnitude lower than the related measurements for D^{*+}
  - ✓ We can potentially improve precision by an order of magnitude using BESIII $D_s^{*}D_s$ data
- The precise measurement on $M(D_s^{*})$ can be used to verify the calculation of lattice QCD , and also provide important input for subsequent work



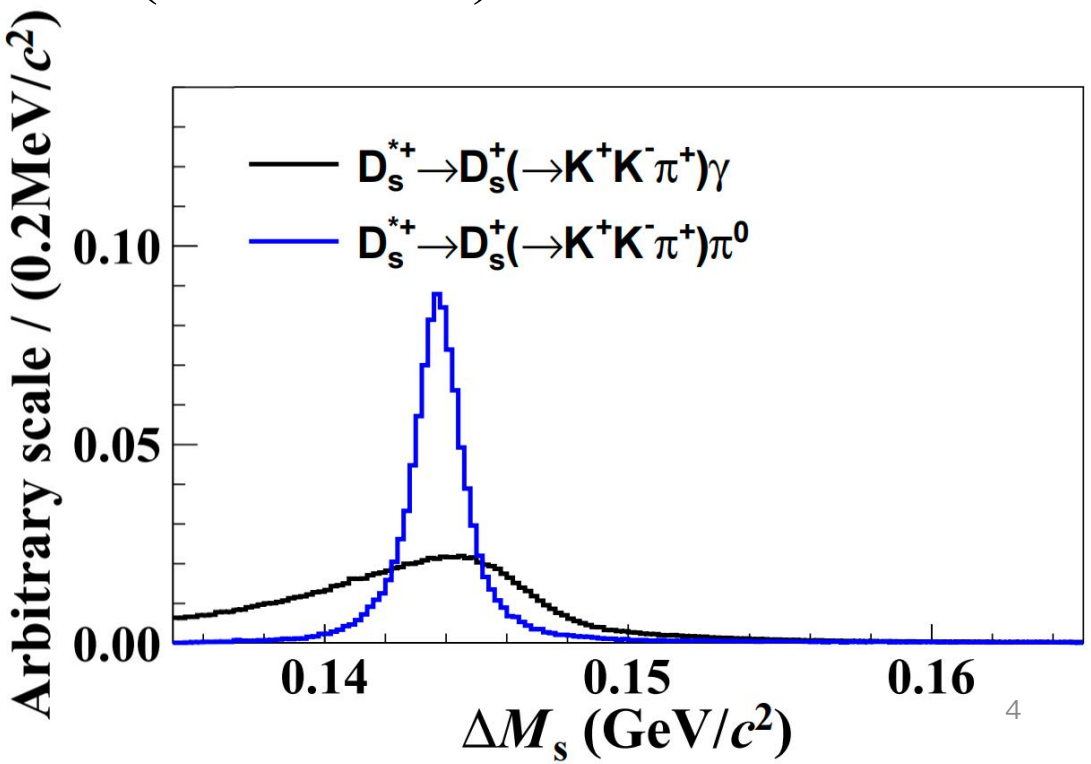


Strategy

Why do we choose the decay channel involving π^0?

1. Lower Q-value → Sharper ΔM_s line shape
2. π^0 mass constraint → Better momentum resolution
3. D^{*+} calibration sample with higher statistics (≈ 20 times)

Decay Chain
$D_s^{*+} \to D_s^+ (\to K^+ K^- \pi^+) \gamma$
$D_s^{*+} \to D_s^+ (\to K^+ K^- \pi^+) \pi^0$



Strategy

(0.140660 GeV)

MC fit = MC input + bias

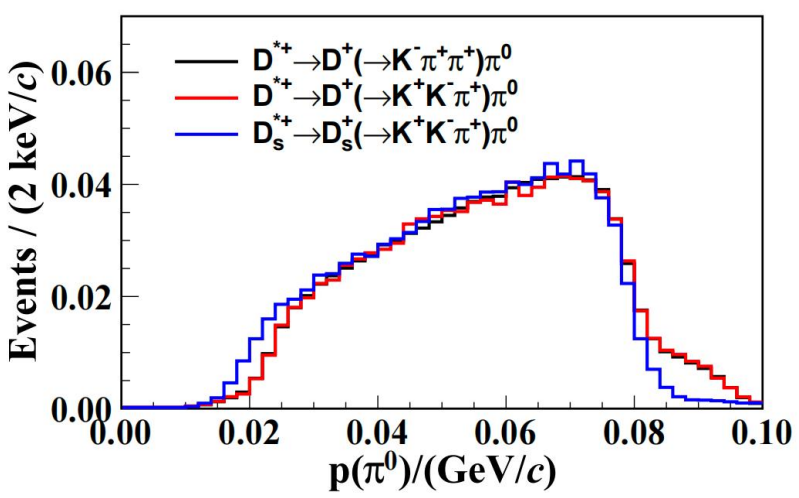
Data fit = **True value** + bias

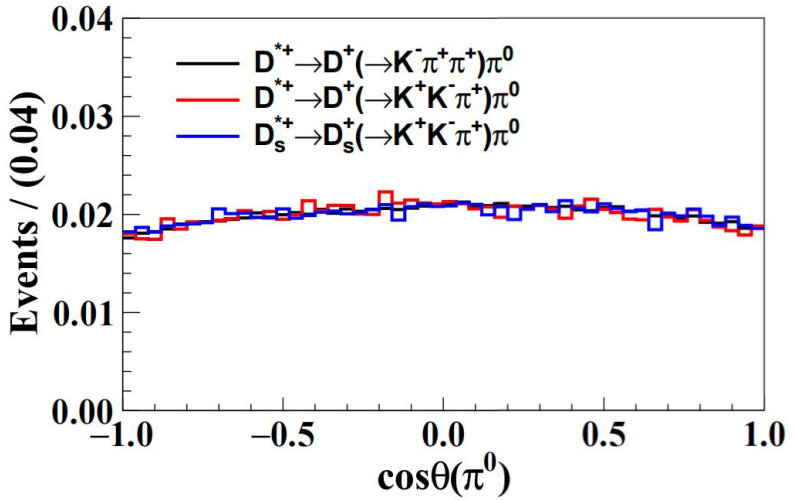
Pole mass **(measured)**

unmodeled detector effects (π^0 energy)

- A major source of systematic uncertainties in this analysis is the calibration of π^0 energy

	Decay Chain	Data Sample
Calibrate	(a) $D^{*+} \to D^+ (\to K^- \pi^+ \pi^+) \pi^0$	E_{cm}=4.178GeV L = 3.19 fb^{-1}
Validate	(b) $D^{*+} \to D^+ (\to K^+ K^- \pi^+) \pi^0$	
Measure	(c) $D_s^{*+} \to D_s^+ (\to K^+ K^- \pi^+) \pi^0$	





Fit model

- Signal model : We used a sum of three probability density functions (PDF) to describe the mass difference between D_s^{*+} and D_s^+ : (same as BABAR 2017[1])
  - ✓ Gaussian (G)
  - ✓ Crystal Ball (CB)
  - ✓ Bifurcated Gaussian (BfG)

$$\begin{aligned}\mathcal{S}(\Delta M) = & f_1 \mathrm{G}(\Delta M; \Delta m_s + \delta_{\Delta m_s}, (1+\epsilon)\sigma_1) \\ & + (1-f_1)\left[f_2 \mathrm{CB}(\Delta M; \Delta m_s + \delta_{\Delta m_s}, (1+\epsilon)\sigma_2, \alpha, n)\right. \\ & \left. + (1-f_2)\mathrm{BfG}(\Delta M; \Delta m_s + \delta_{\Delta m_s}, (1+\epsilon)\sigma_3^L, (1+\epsilon)\sigma_3^R)\right]\end{aligned}$$

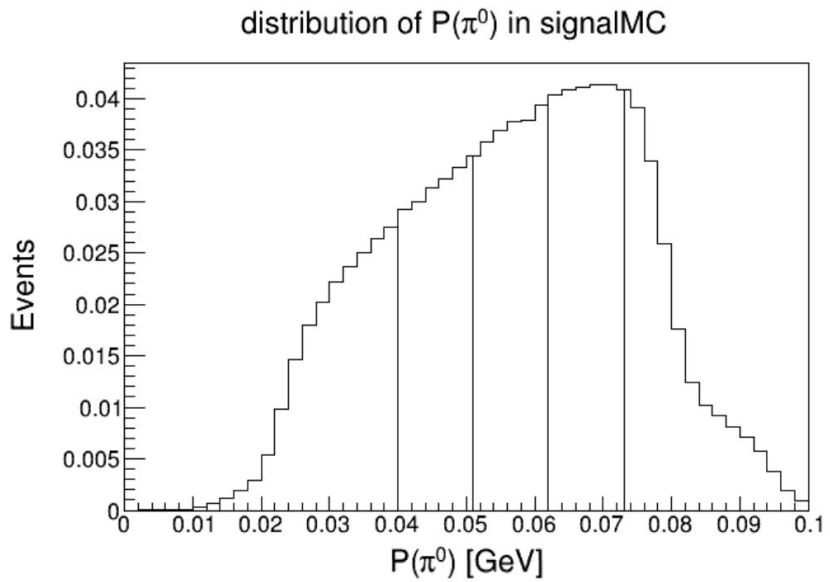
	magenta	red	blue
signal MC fit	$M(D_{(s)}^{*+}) - M(D_{(s)}^+)$	fixed	floating
data fit	$M(D_{(s)}^{*+}) - M(D_{(s)}^+)$	floating	fixed

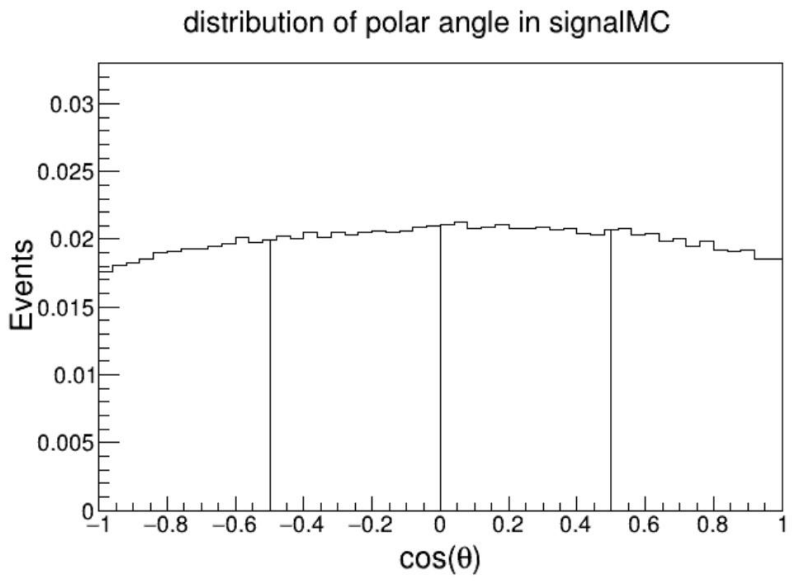
- Background model : We used RooKeysPdf to describe the signal-removed inclusive MC

[1]Phys. Rev. Lett. 119, 202003

π^0 Correction

- The π^0 momentum distribution ($P(\pi^0)$) of the three decay chains is checked (Page 4) , and the results are consistent , and we believe that the dynamics of the three decay chains are similar





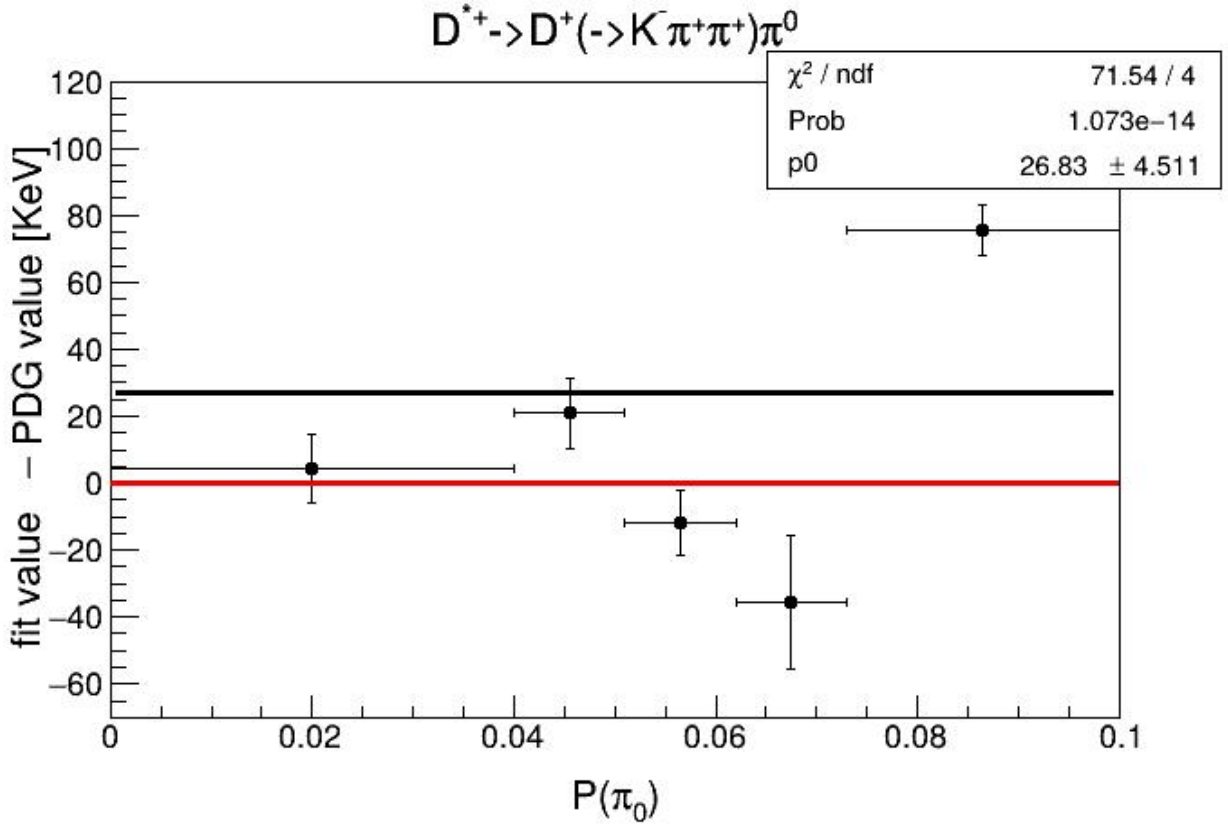
- Events are evenly divided into 5(4) bins according to $P(\pi^0)$(polar angle) distribution

a) $D^{*+} \to D^+ (\to K^- \pi^+ \pi^+) \pi^0$ (calibrate and correct)
b) $D^{*+} \to D^+ (\to K^+ K^- \pi^+) \pi^0$ (validate)
c) $D_s^{*+} \to D_s^+ (\to K^+ K^- \pi^+) \pi^0$ (measure)

π^0 Correction

Decay chain (a) is studied first:

- Fit the whole and record the tail parameters α and n of Crystal Ball (CB) PDF
- Keep the above two parameters unchanged when fitting in each bin
- The difference between the PDG value and the fit value in each bin before correction



a) $D^{*+} \rightarrow D^+ (\rightarrow K^- \pi^+ \pi^+) \pi^0$ (calibrate and correct)
b) $D^{*+} \rightarrow D^+ (\rightarrow K^+ K^- \pi^+) \pi^0$ (validate)
c) $D_s^{*+} \rightarrow D_s^+ (\rightarrow K^+ K^- \pi^+) \pi^0$ (measure)

π^0 Correction

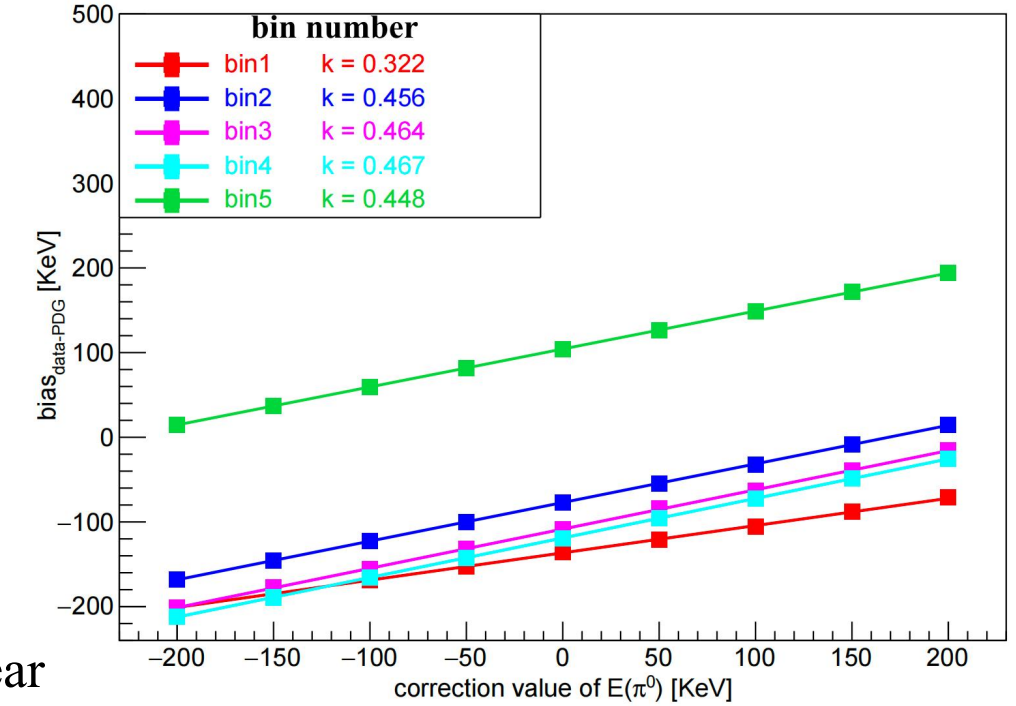
- Add a correction to the π^0 energy (ΔE) for each event of decay chain (a)

$$\Delta E_{\pi 0} = 0\ ,\ \pm 100\ ,\ \pm 200\ \text{KeV}$$

$$E_{\pi 0} \rightarrow E_{\pi 0} + \Delta E_{\pi 0}$$

$$P_{\pi 0} \rightarrow P_{\pi 0} * \varepsilon_{\pi 0} = P_{\pi 0} * (1 + (2E_{\pi 0}\Delta E_{\pi 0} + \Delta E_{\pi 0}\Delta E_{\pi 0})/P_{\pi 0}P_{\pi 0})^{1/2}$$

$$m(D_s^{*+}) - m(D_s^{+}) \rightarrow m(D_s^{*+})' - m(D_s^{+})$$



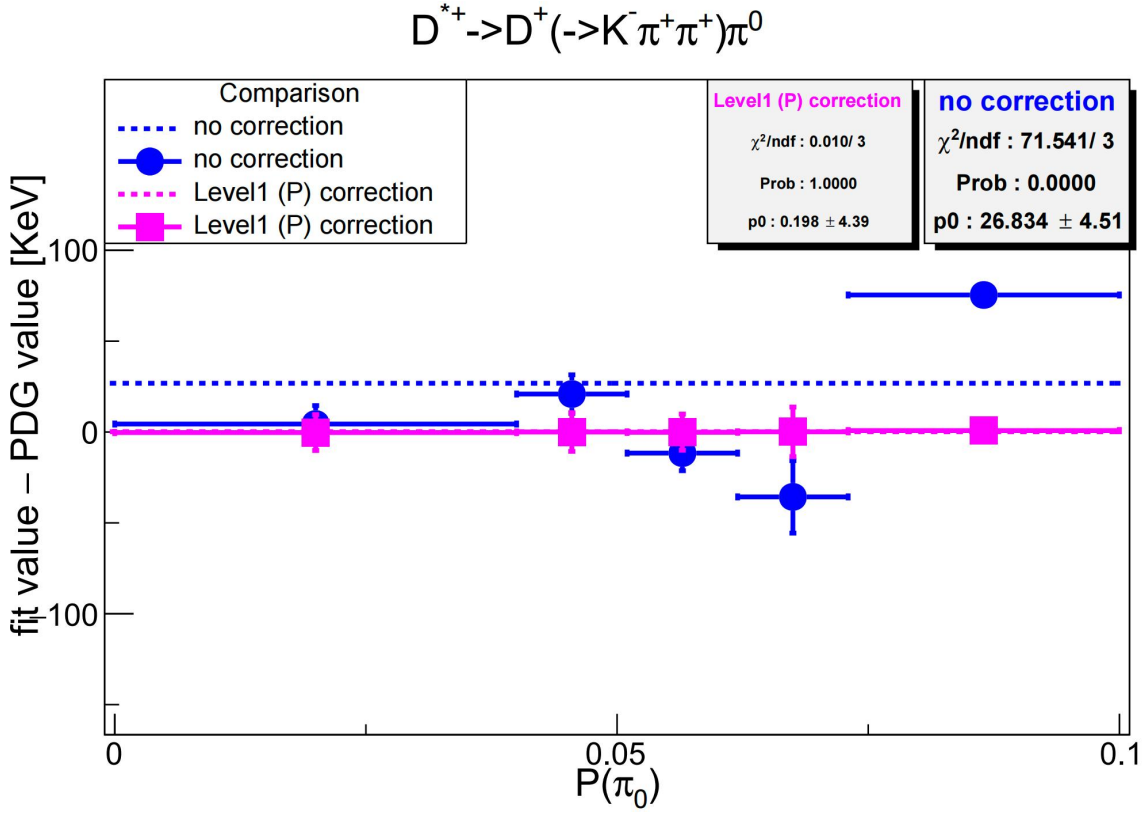
- The relationship between Y-axis and X-axis is almost linear
- The slope in each bin is almost equal

- Y-axis = $m_{correction}$ = $m(D_s^{*+})'$ - $m(D_s^{*+})$
- X-axis = $\Delta E_{\pi 0}$

a) $D^{*+} \rightarrow D^{+} (\rightarrow K^{-} \pi^{+} \pi^{+}) \pi^{0}$ (calibrate and correct)
b) $D^{*+} \rightarrow D^{+} (\rightarrow K^{+} K^{-} \pi^{+}) \pi^{0}$ (validate)
c) $D_s^{*+} \rightarrow D_s^{+} (\rightarrow K^{+} K^{-} \pi^{+}) \pi^{0}$ (measure)

π^0 Correction

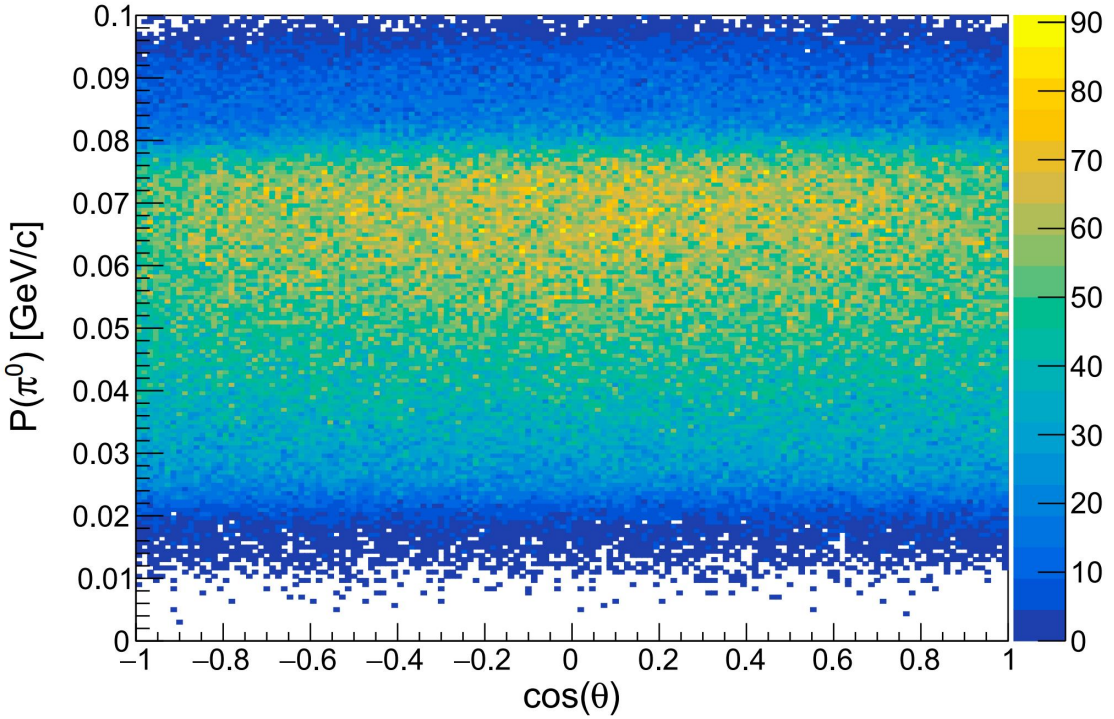
- The fitted mean value of the signal MC model can be changed by correcting E(π^0) in the MC sample
- This relationship can be used to correct the bias between MC and data
- $k = bias_{data\text{-}PDG}/\Delta E \rightarrow \Delta E = bias_{data\text{-}PDG}/k$
- So far we have obtained the values for $bias_{data\text{-}PDG}$ and k



a) $D^{*+} \to D^{+} (\to K^{-} \pi^{+} \pi^{+}) \pi^{0}$ (calibrate and correct)
b) $D^{*+} \to D^{+} (\to K^{+} K^{-} \pi^{+}) \pi^{0}$ (validate)
c) $D_s^{*+} \to D_s^{+} (\to K^{+} K^{-} \pi^{+}) \pi^{0}$ (measure)

π^0 Correction

- Check the correlation between P(π^0) and cos(θ) in the decay chain (a)

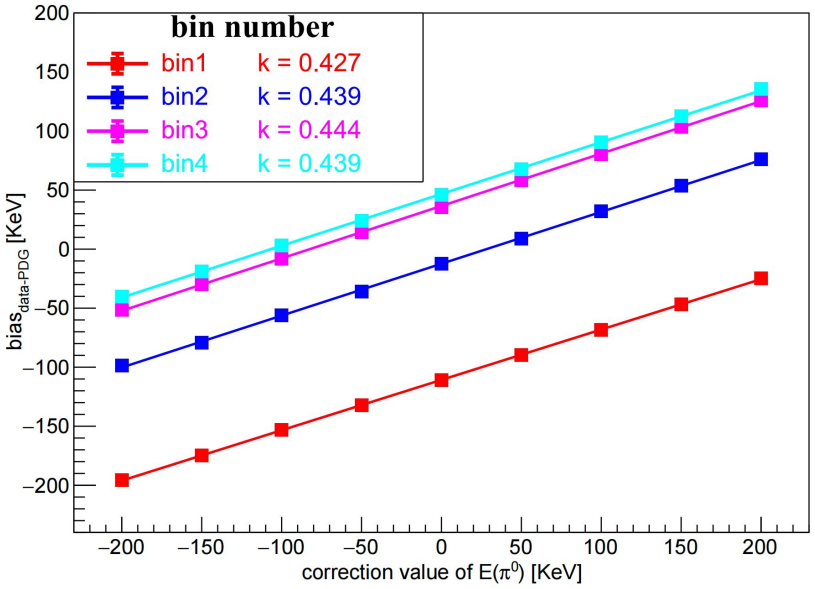


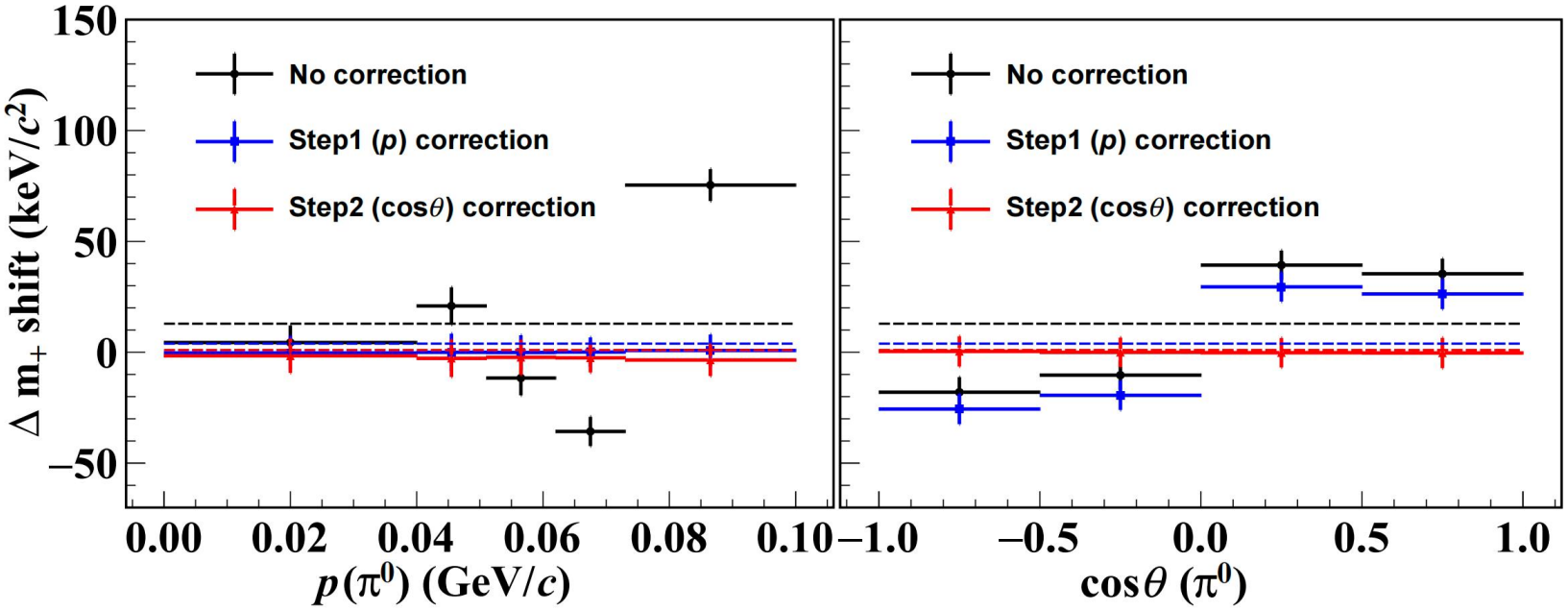
- There is no obvious correlation between P(π^0) and cos(θ)

a) $D^{*+} \rightarrow D^+ (\rightarrow K^- \pi^+ \pi^+) \pi^0$ (calibrate and correct)
b) $D^{*+} \rightarrow D^+ (\rightarrow K^+ K^- \pi^+) \pi^0$ (validate)
c) $D_s^{*+} \rightarrow D_s^+ (\rightarrow K^+ K^- \pi^+) \pi^0$ (measure)

π^0 Correction

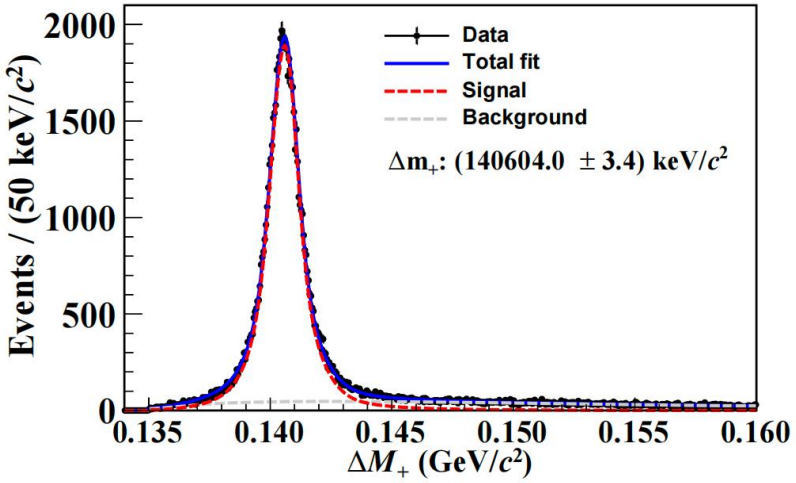
- That of polar angle-binned satisfies the same relationship.



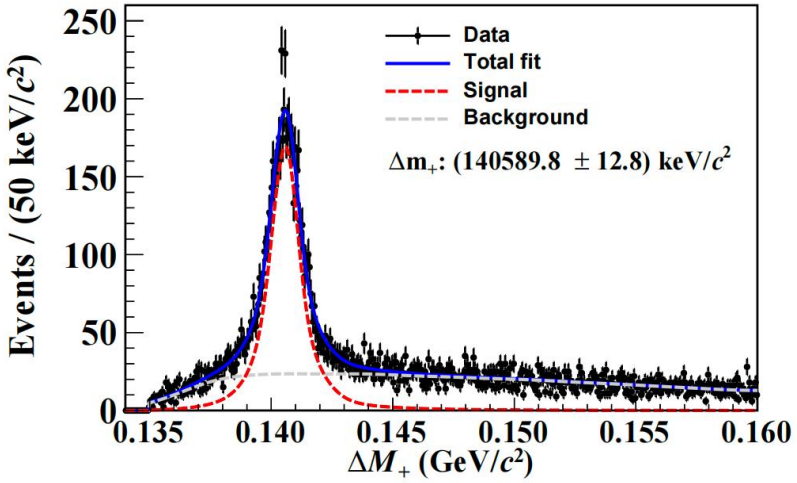


π^0 Correction

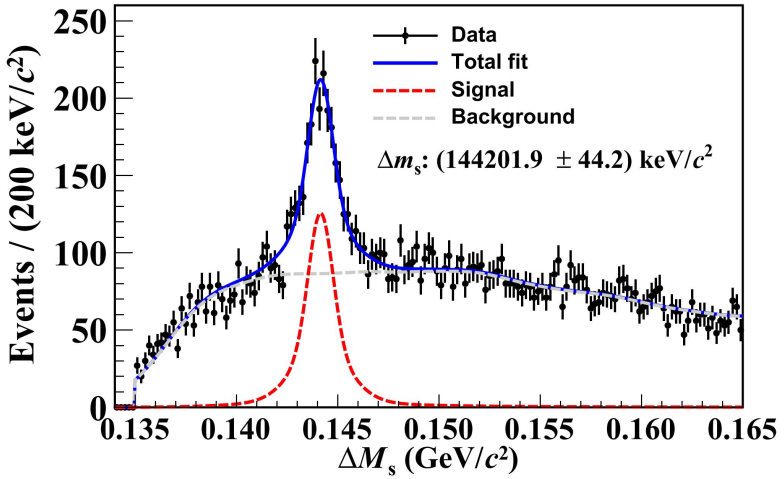
- Fit results of data with Level2 correction



(a)



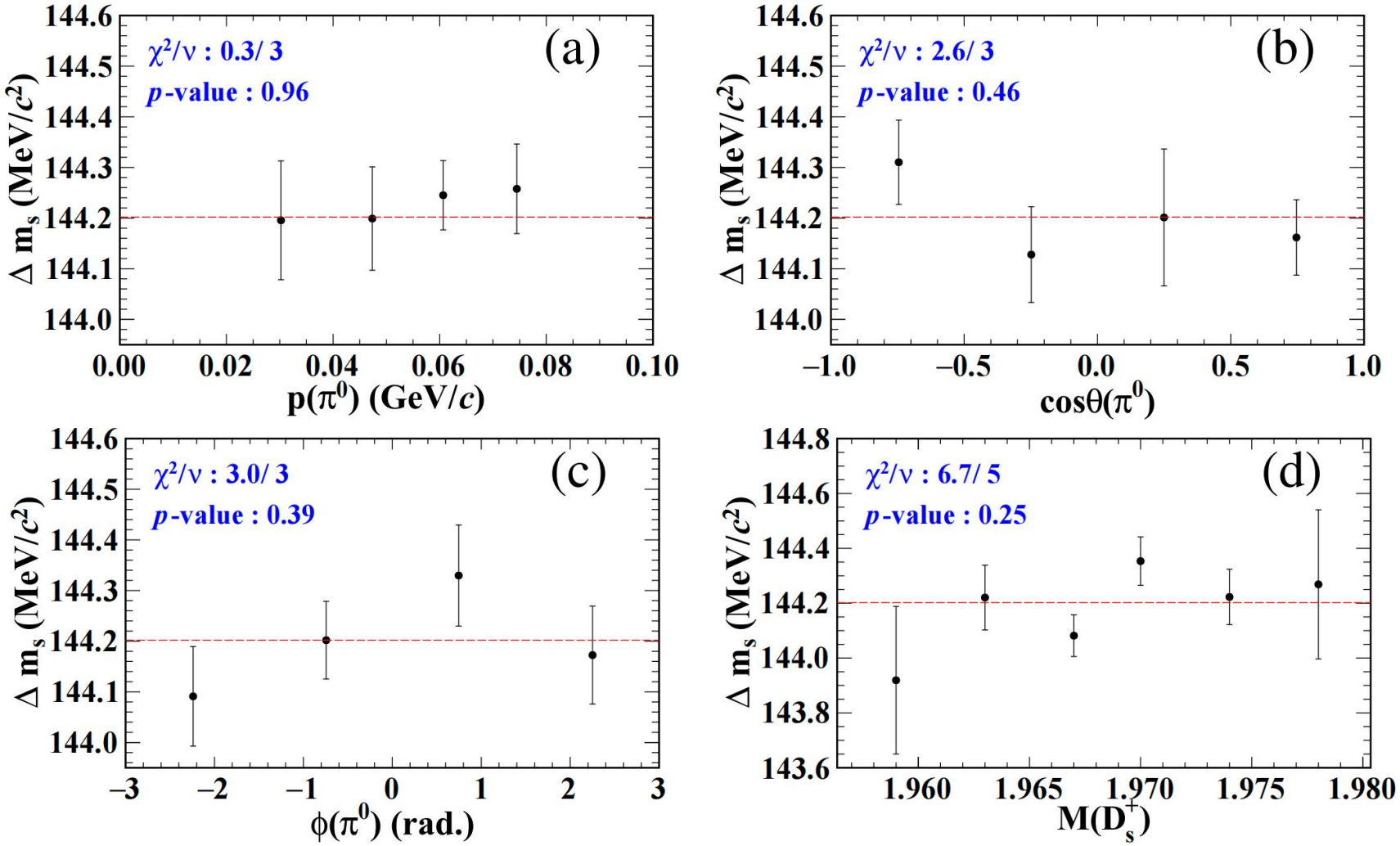
(b)



(c)

Label	Decay Chain	no-correction [keV/c^2]	Level1 (P) correction [keV/c^2]	Level2 ($\cos\theta$) correction [keV/c^2]	PDG value [keV/c^2]
(a)	$D^{*+} \to D^+(\to K^-\pi^+\pi^+)\pi^0$	140615.9 ± 3.4	140606.9 ± 3.4	140604.0 ± 3.4	140603 ± 15
(b)	$D^{*+} \to D^+(\to K^+K^-\pi^+)\pi^0$	140601.8 ± 12.8	140592.7 ± 12.8	140589.8 ± 12.8	140603 ± 15
(c)	$D_s^{*+} \to D_s^+(\to K^+K^-\pi^+)\pi^0$	144216.1 ± 44.2	144206.2 ± 44.2	144201.9 ± 44.2	143800 ± 400

Systematic Uncertainty



Source	
π^0 momentum dependence	p
	cosθ
	cosφ
$m(D_s^+)$ dependence	
Signal model parametrization	
Background modeling	
Binned correction	
Binned of $P(\pi^0)$	
Cut on $M(\gamma\gamma)$	
Input from PDG	

If the value of $\chi^2 / \nu < 1$, then no systematic uncertainty is assigned .

So $\sigma_{syst.} = \sigma_{stat.} * \sqrt{(\chi^2 / \nu - 1)}$ = 25.5 keV systematic uncertainty is assigned.

Systematic Uncertainty

Source	Δm_s systematic $[\mathrm{keV}/c^2]$
$M(D_s^+)$ dependence	25.5
Signal model parametrization	5.5
Background modeling	Negligible
$D^{*+} \to D^+(\to K^-\pi^+\pi^+)\pi^0$ sample size	9.1
Interval on $p(\pi^0)$ & $\cos\theta(\pi^0)$	11.5
Total	29.9

Systematic Uncertainty

- Fit ranges of ΔM
  - Test with different ΔM upper limits : 0.158, 0.160, 0.162, 0.164, 0.166, 0.168
- Calibrated $E_{c.m.}$
  - Subtracting one σ of $E_{c.m.}$ and regenerate real data
- Dalitz-plot
  - 4 disjoint subset ranges of the Dalitz-plot
- Cut on recoil mass
  - Test with new limit : $|(M_{rec}-1.96835)| < 0.012, 0.014, 0.016, 0.017, 0.025$
- Momentum scale of charged tracks
  - Decrease the momentum magnitude of the three charged tracks by 0.05%
- Charge check
  - Measure the Δm_s for D_s^{*+} and D_s^{*-} decays separately
- Signal model
  - Alternative signal PDF of CB + BfG

All tests show consistent results

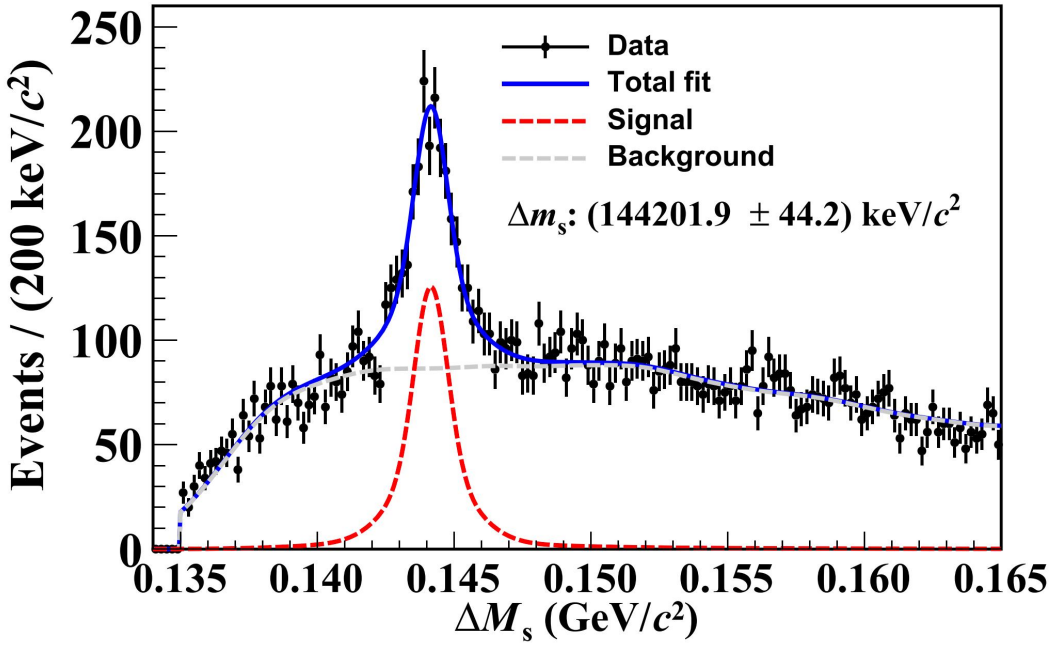
Results

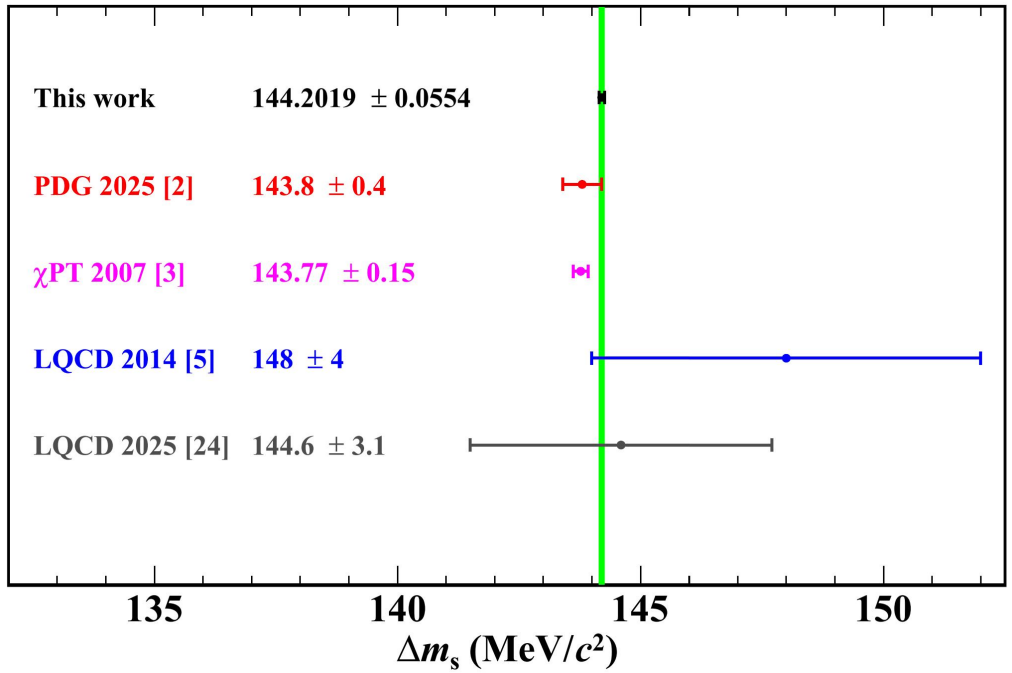
- Consistent with the world average, precision seven times better
- Testing SU(3) flavor symmetry with the CMS results.

$$\Delta m_B \equiv (m_{\bar{B}_s^{*0}} - m_{\bar{B}_s^0}) - (m_{\bar{B}^{*0}} - m_{\bar{B}^0}) = 3.94 \pm 0.14 \text{ MeV}/c^2 \text{ [1]}$$

$$\Delta m_D \equiv (m_{D_s^{*+}} - m_{D_s^+}) - (m_{D^{*+}} - m_{D^+}) = 3.599 \pm 0.055 \text{ MeV}/c^2$$

$\Delta m_D / \Delta m_B = 0.91 \pm 0.04$
differs from $m_b/m_c \sim 3.29$





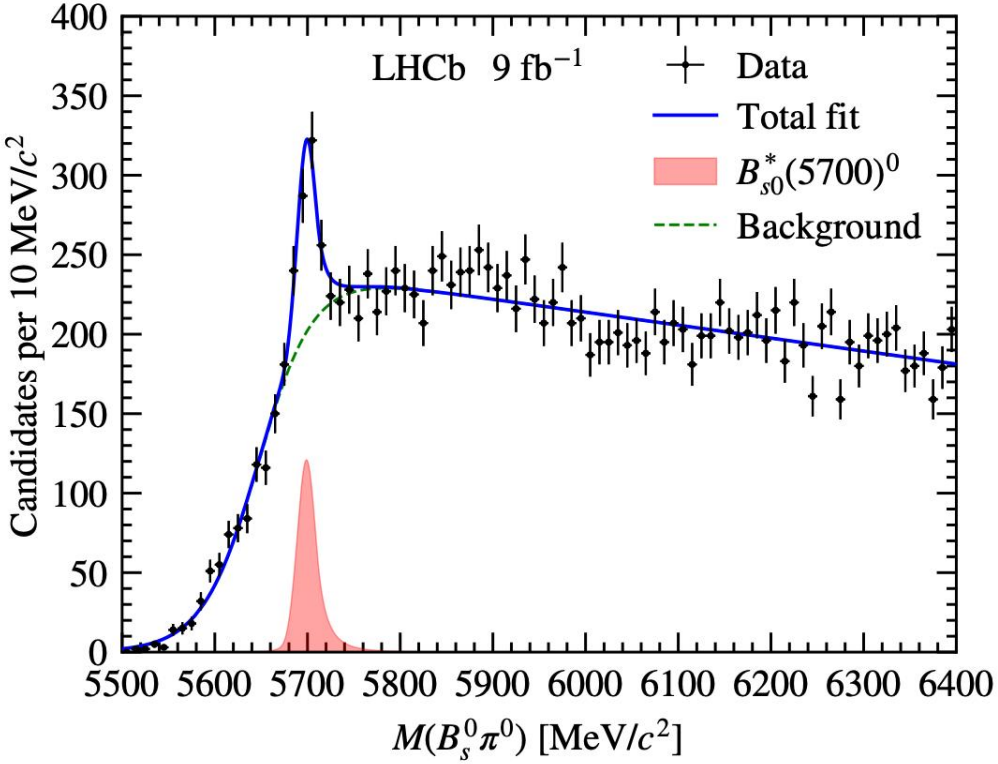
[1] CMS, Phys. Rev. Lett. 136, 031902 (2026)

Discussion

- Comparing our precise Δm_s with the $D_{s0}^*(2317)$–$D_{s1}(2460)$ mass splitting tests the doublet hypothesis (consistent with zero), motivating a more precise $D_{s0}^*(2317)$ and $D_{s1}(2460)$ mass measurement

- [1]LHCb's new $B_{s0}^*(5700)^0$ — the beauty analogue of $D_{s0}^*(2317)$ — hints at an analogous beauty doublet, which together with our future measurements of $D_{s0}^*(2317)$ and $D_{s1}(2460)$ will offer a charm–beauty cross-check

- The π^0 energy-correction strategy can be applied to a precise measurement of the Ξ^0 mass



[1] LHCb, arXiv:2609.25178

Summary and Outlook

- The measured mass difference of $D_s^{*+} - D_s^+$ is

$$\Delta m_s = 144{,}201.9 \pm 44.2(\text{stat}) \pm 29.9(\text{syst}) \pm 15.0(\text{input}),$$

with a precision seven times better than the current world average.

- The momentum calibration method employed in this research can be applied to any measurement involving soft π^0 reconstruction, e.g., measuring the masses of $D_{s0}^*(2317)$, $D_{s1}(2460)$ and Ξ^0.

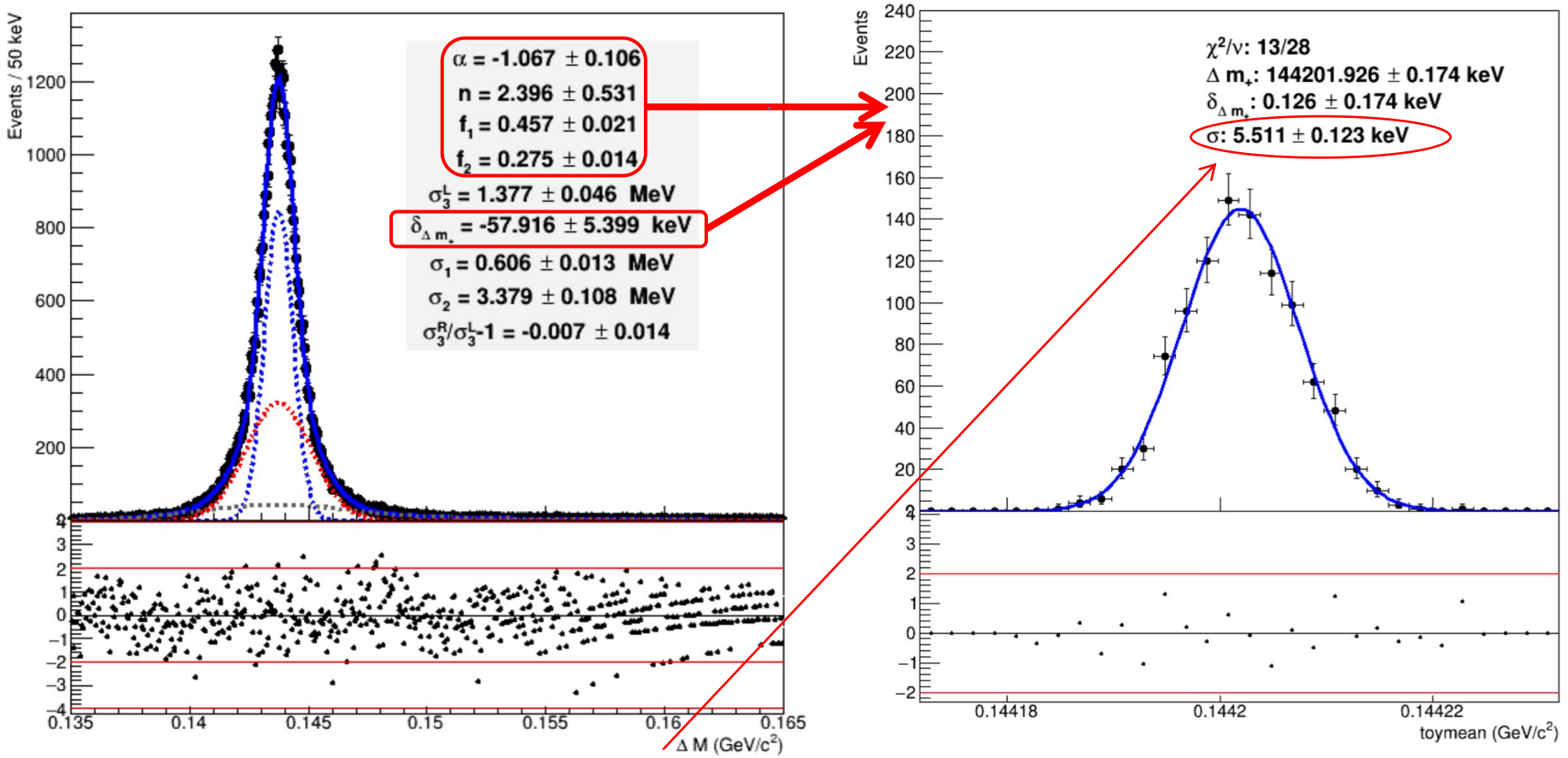
backup

Systematic Uncertainty

- π^0 momentum dependence: choose disjoint subset ranges with approximately equivalent statistics (for p, cosθ and ϕ) .
- m(D_s^+) dependence: use the same method as the last one .
- Signal model parametrization: choose a different fixed value for the fit parameter α, n, f_1 and f_2 .
- Background modeling: use ARGUS function instead of MC shape partially .
- Binned correction: change the correction value and record the change in the fitting result .
- Binned of P(π^0): splitting the last bin of p(π^0) into two and refit.
- Cut on M(γγ): widen the M(γγ) window to be 0.115 < M(γγ) < 0.150 GeV/c^2.
- Input from PDG: one of the dominant systematic errors comes from the errors transmitted by the PDG input values .

Source	
π^0 momentum dependence	p
	cosθ
	cosϕ
m(D_s^+) dependence	
Signal model parametrization	
Background modeling	
Binned correction	
Binned of P(π^0)	
Cut on M(γγ)	
Input from PDG	

Systematic Uncertainty

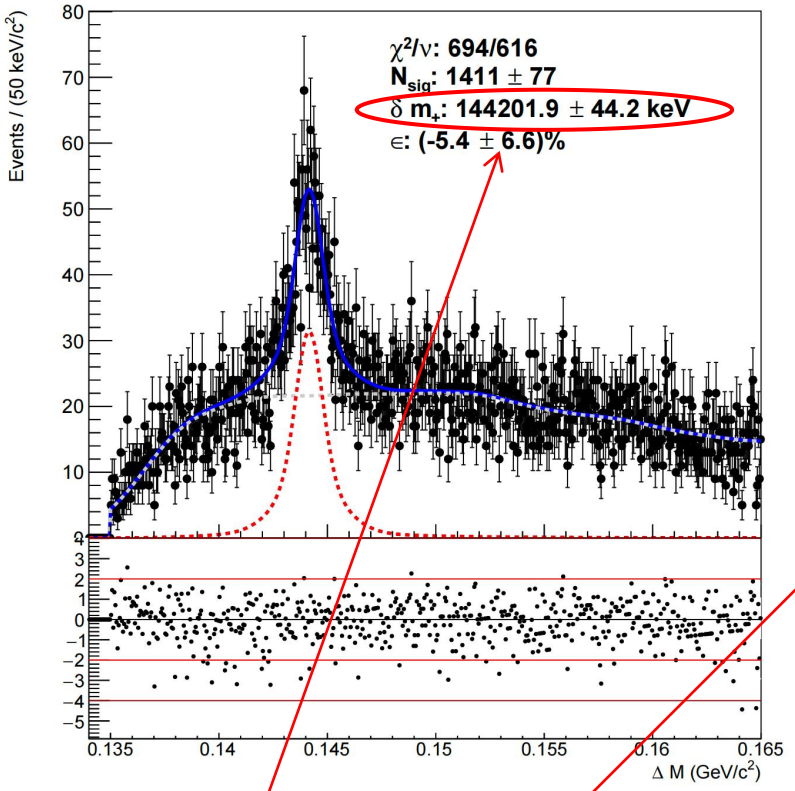


Source	
π^0 momentum dependence	p
	cosθ
	cosφ
$m(D_s^+)$ dependence	
Signal model parametrization	
Background modeling	
Binned correction	
Binned of $P(\pi^0)$	
Cut on $M(\gamma\gamma)$	
Input from PDG	

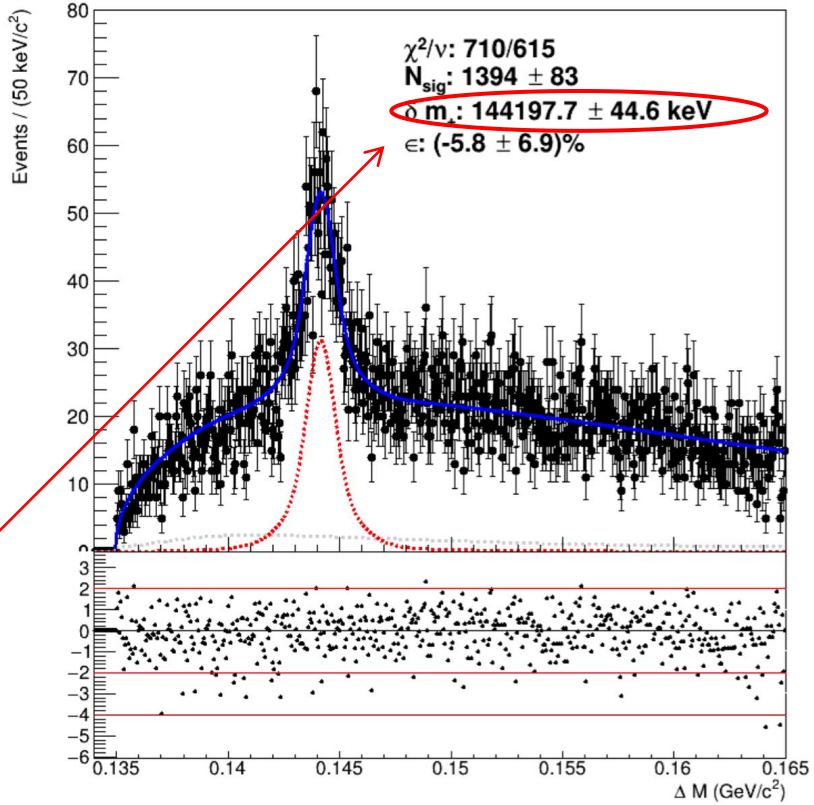
Generate 1000 sets of correlated random numbers of shape parameters based on the covariance matrix from signal MC fit , and check the variations in fit value.

So 5.5 keV systematic uncertainty is assigned.

Systematic Uncertainty



RooKeysPDF
(all background)



RooKeysPDF+ArgusPDF

(one kind of physical background：π^0 from D*)

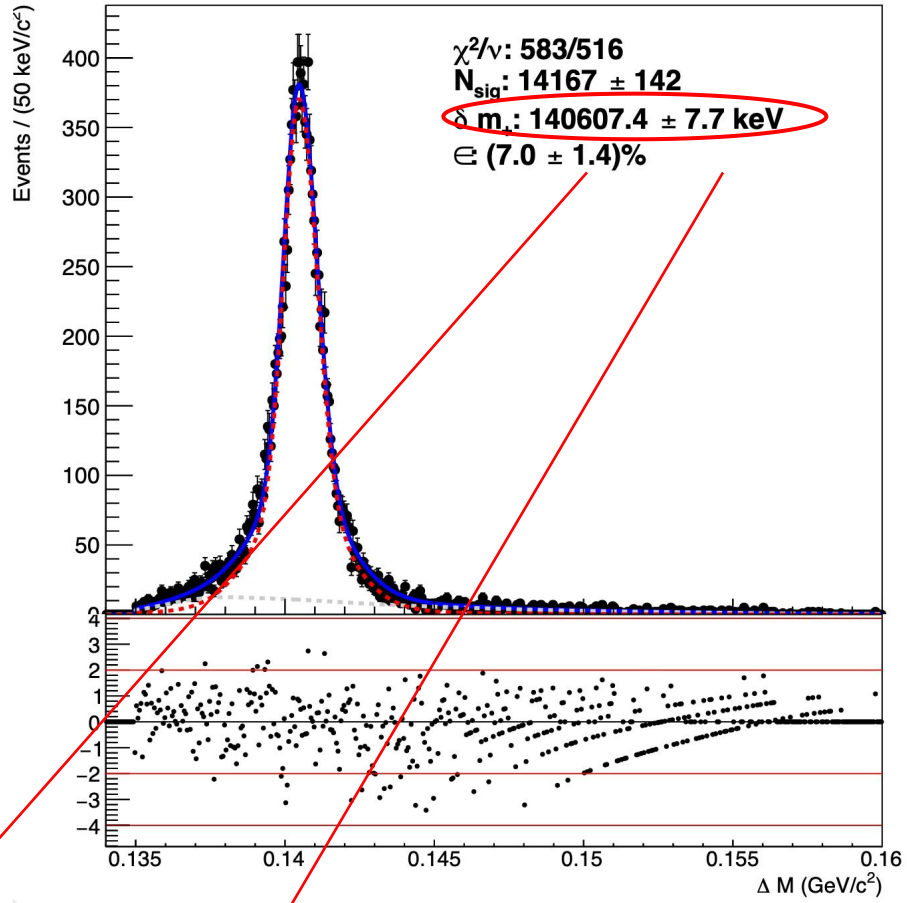
δm - δm’ = 4.2 keV , satisfying the Barlow test, so no systematic error is assigned .

Source	
π^0 momentum dependence	p
	cosθ
	cosφ
$m(D_s^+)$ dependence	
Signal model parametrization	
Background modeling	
Binned correction	
Binned of $P(\pi^0)$	
Cut on M(γγ)	
Input from PDG	

Systematic Uncertainty

Such as bin1 correction:

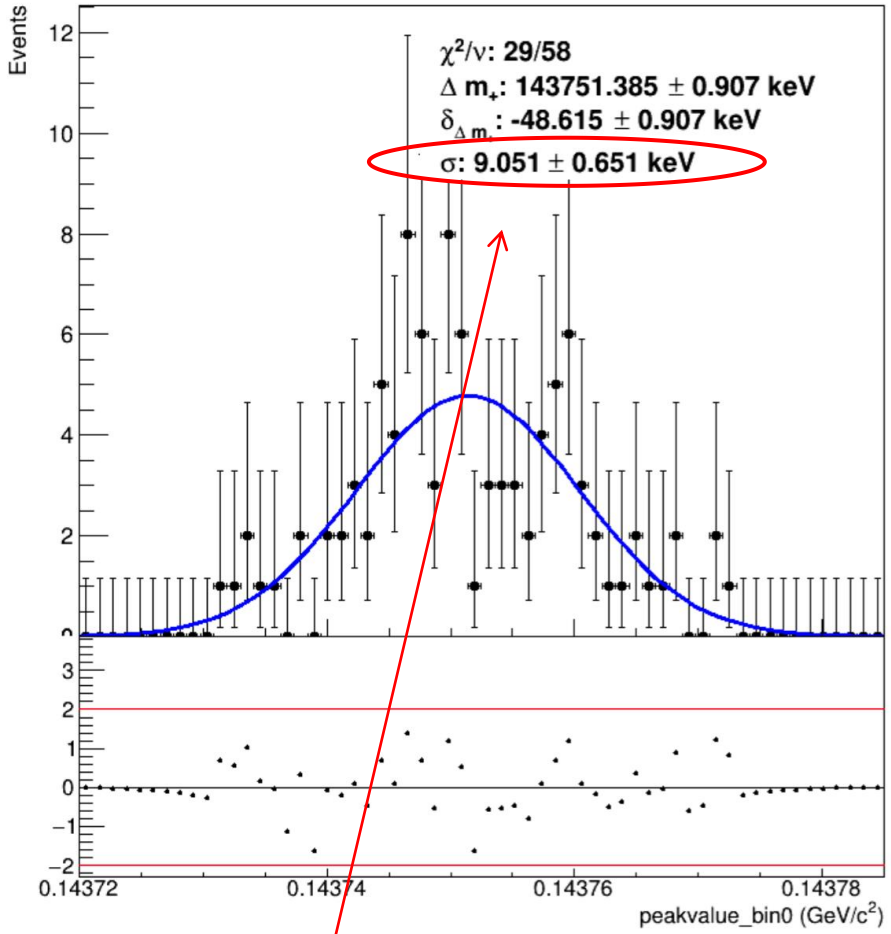
we study on 100 datasets where the correction values are generated from Gaussion distribution whose mean value equals to the fit bias and sigma value equals to the fit error of deacy chain (a)



Gaussion mean	140607.4(fit result)−140603.0(PDG)
Gaussion sigma	7.7(fit result)

Source	
π^0 momentum dependence	p
	cosθ
	cosφ
$m(D_s^+)$ dependence	
Signal model parametrization	
Background modeling	
Binned correction	
Binned of $P(\pi^0)$	
Cut on $M(\gamma\gamma)$	
Input from PDG	

Systematic Uncertainty



Source	
π^0 momentum dependence	p
	cosθ
	cosφ
$m(D_s^+)$ dependence	
Signal model parametrization	
Background modeling	
Binned correction	
Binned of $P(\pi^0)$	
Cut on $M(\gamma\gamma)$	
Input from PDG	

We fixed the correction values on the 100 datasets and record the change of the fit result .

Systematic of 9.1 keV from this method

Systematic Uncertainty

Adjust the binning scheme of p(π^0) and polar angle

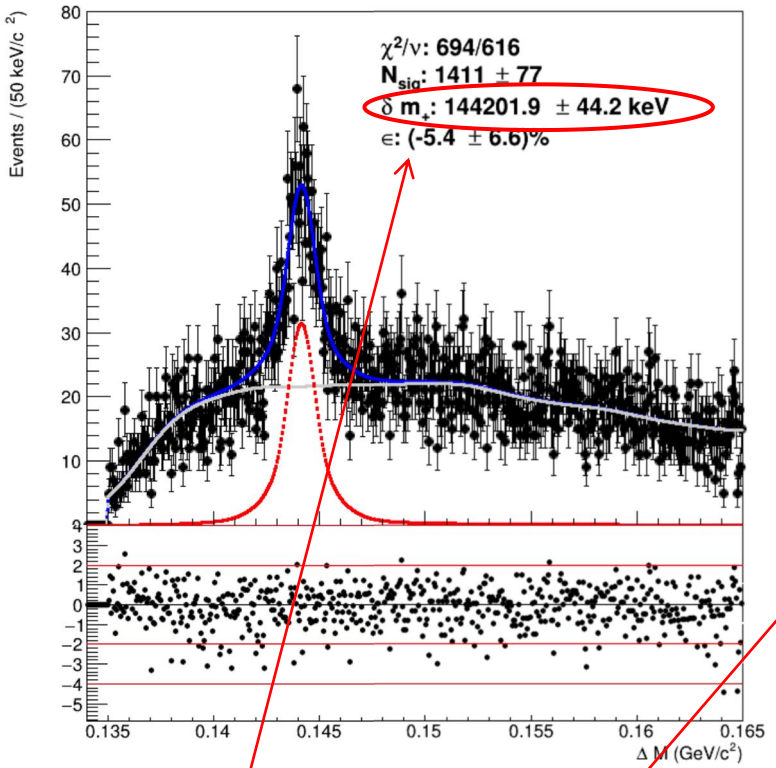
binning range	Δm_s shift [keV]
5 -bin for momentum magnitude, 4-bin for polar angle (original range)	0
5 -bin for momentum magnitude, 3-bin for polar angle	−0.7
5 -bin for momentum magnitude, 5-bin for polar angle	−1.6
4 -bin for momentum magnitude, 4-bin for polar angle	−5.5
6 -bin for momentum magnitude, 4-bin for polar angle	0.5
6 -bin for momentum magnitude (splitting the last bin into two), 4-bin for polar angle	11.5

So 11.5 keV systematic error is assigned.

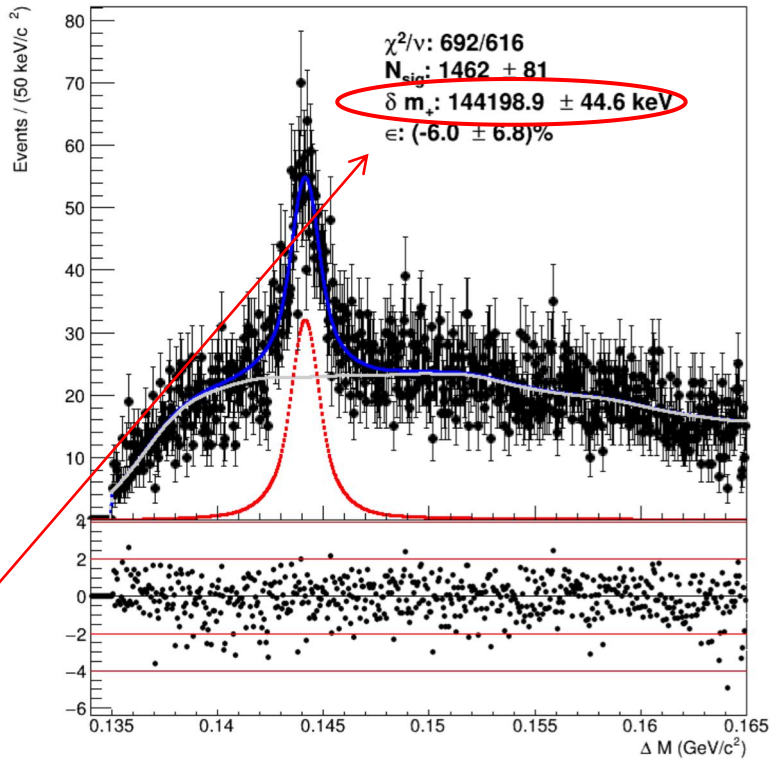
Source	
π^0 momentum dependence	p
	cosθ
	cosφ
m(D_s^+) dependence	
Signal model parametrization	
Background modeling	
Binned correction	
Binned of P(π^0)	
Cut on M(γγ)	
Input from PDG	

Systematic Uncertainty

widen the M(γγ) window to be $0.115 < M(\gamma\gamma) < 0.150$ GeV/c^2



original scheme



new scheme

δm - δm' = 3 keV , satisfying the Barlow test, so no systematic error is assigned .

Source	
π^0 momentum dependence	p
	cosθ
	cosφ
$m(D_s^+)$ dependence	
Signal model parametrization	
Background modeling	
Binned correction	
Binned of $P(\pi^0)$	
Cut on M(γγ)	
Input from PDG	