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Study of $K^*(892)$ mass and width splitting caused by model difference*

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Abstract According to the new $K^*(892)^0$ and $K^*(892)^-$ masses reported by the BELLE experiment and the $K^*(892)^0$ mass reported by the FOCUS experiment, mass splitting between neutral and charged $K^*(892)$ becomes very small. This is significantly different from the current world average values given by the Particle Data Group 2008. We find that there are differences between models used to fit the $K^*(892)$ decay invariant mass spectra in different measurements and study the model dependence in the measurement of $K^*(892)$ parameters. We refit the $K^*(892)^0$ mass spectra of the BELLE and FOCUS experiments with the formula used by BELLE in fitting $K^*(892)^-$ to get new mass and width. After refitting, the $K^*(892)^0$ mass of the BELLE experiment becomes 1.4 MeV/c^2 larger than the initial value and that of the FOCUS experiment is 1 MeV/c^2 smaller than the initial value. We also fit the spectra of some other experiments to extract the $K^*(892)$ parameters using the BELLE $K^*(892)^-$ parametrization.

Key words K^* resonance parameters, Breit-Wigner function

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1 Introduction

Charged and neutral $K^*(892)$ are isospin partners with $I(J^P)=\frac{1}{2}(1^-)$, and in the quark model $\bar{K}^{*0}=\bar{d}s$, $K^{*0}=d\bar{s}$, $K^{*+}=u\bar{s}$, and $K^{*-}=\bar{u}s$. In the absence of isospin breaking, $K^*(892)^{\pm}$ and $K^*(892)^0$ must have equal mass and decay width. The mass splitting between charged and neutral $K^*(892)$ is caused by the mass difference of the u-d quark (the QM-mass difference) and the electromagnetic interactions inside hadrons (the EM-mass difference), i.e.,

$$\Delta m = M_{K^{*0}} - M_{K^{*\pm}} = \Delta m_{QM} + \Delta m_{EM} = (M_{K^{*0}} - M_{K^{*\pm}})_{QM} + (M_{K^{*0}} - M_{K^{*\pm}})_{EM}\,. \quad (1)$$

There are many theoretical explanations for the mass splitting of $K^*(892)$ based on different approximations, since it is still hard to calculate it from the first principle of quantum chromodynamics (QCD) today. With the effective hadronic theory[1], Δm_{QM} is found between 2.04 MeV/c^2 and 6.78 MeV/c^2, while with the chiral constituent quark model $\Delta m_{QM} = \frac{1}{2}(m_d - m_u) = 3.07\pm0.18$ MeV/c^2[2]. Usually, the EM-masses of neutral hadrons are smaller than those of their charged partners, but there are abnormal cases sometimes. According to the $K^*(892)$ experimental results and the theoretical Δm_{QM} values given above, there is a probability that the EM-mass of neutral $K^*(892)$ is larger than that of the charged one.

Recently, the authors of Ref. [3] gave a new mass splitting calculation. In the calculation, Δm_{QM} has the same value as that given in Ref. [2], and a normal EM-mass value $\Delta m_{EM} = -1.76$ MeV/c^2 is used. So they gave the mass splitting as $\Delta m \approx 1.3$ MeV/c^2.

It is well known that the resonance parameters depend on the parametrization of the Breit-Wigner function, especially for wide resonances. Different parametrization will introduce difference in the resonance parameters. The reason why the formulas used to fit $K^*(892)$ spectra are different is that they are calculated from theories with different assumptions.

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In general, $K^*(892)\to K\pi$ mass distribution has the form

$$\frac{dN}{dm}\propto|\mathcal{M}|^2P(m)\,, \tag{2}$$

where m is the invariant mass of $K\pi$ and $P(m)$ is the momentum of K in the $K\pi$ system. The matrix element $|\mathcal{M}|^2$ includes the Breit-Wigner propagator multiplying $P^2(m)$ for a vector decaying into two pseudoscalars, and may also include some correcting factors. The $P(m)$ in Eq. (2) comes from two body decay phase space. So we have

$$\frac{dN}{dm}\propto\left|\frac{1}{m^2-M_0^2+iM_0\Gamma(m)}P(m)\right|^2P(m)\times cf\,, \tag{3}$$

where M_0 and Γ are the mass and width of $K^*(892)$ respectively, and cf is a correcting factor.

In this paper we examine the models used in describing the $K^*(892)$ resonance, and try to fit the data from different experiments with the same model, to obtain a better estimation of the mass and width difference between the neutral and charged $K^*(892)$ mesons.

There have been several experimental measurements of the mass and width of the neutral and charged $K^*(892)$. The world average of Δm is 6.7 ± 1.2 MeV/c^2 from direct measurements of the mass difference[4], while based on the world average of the masses[4] $M_{K^{*0}}=896.00\pm0.25$ MeV/c^2 and $M_{K^{*\pm}}=891.66\pm0.26$ MeV/c^2, one gets $\Delta m_{\rm indirect}$ as 4.34 ± 0.36 MeV/c^2. So except for the new BELLE measurement of $K^*(892)^-$ listed separately, we estimate the $K^*(892)$ mass splitting as

$$\Delta m_{\rm PDG08}\sim4-8\,{\rm MeV}/c^2\,. \tag{4}$$

The world averages of $K^*(892)^\pm$ and $K^*(892)^0$ widths are 50.8 ± 0.9 MeV/c^2 and 50.3 ± 0.6 MeV/c^2 respectively[4], which are consistent with each other within errors. But the $K^*(892)$ widths of different experiments are significantly different and the uncertainty of the width is much larger than that of the masses.

Recently, the BELLE collaboration reported that $M_{K^{*-}}=895.47\pm0.20\pm0.44\pm0.59$ MeV/c^2 and $\Gamma_{K^{*-}}=46.2\pm0.6\pm1.0\pm0.7$ MeV/c^2 from the study of $\tau^-\to K_S\pi^-\nu_\tau$[5], then reported that $M_{K^{*0}}=895.10\pm0.27\pm0.31$ MeV/c^2 and $\Gamma_{K^{*0}}=47.23\pm0.49\pm0.79$ MeV/c^2 from the study of $\tau^-\to K^*(892)^0K^-\nu_\tau$[6]. The FOCUS collaboration reported that $M_{K^{*0}}=895.41\pm0.32^{+0.35}_{-0.43}$ MeV/c^2 and $\Gamma_{K^{*0}}=47.79\pm0.86^{+1.32}_{-1.06}$ MeV/c^2 from the study of $D^+\to K^-\pi^+\mu^+\nu$[7]. The precision of these experiments is high enough to give meaningful measurements of the parameters of $K^*(892)$. From the BELLE and FOCUS results we get $\Delta m=-0.26\pm0.83$ MeV/c^2, and $\Gamma_{K^{*0}}-\Gamma_{K^{*\pm}}=1.17\pm1.58$ MeV/c^2, consistent with zero within errors.

The mass splitting from the three recent measurements somewhat disagrees with the earlier experiments. This indicates that some inconsistency must exist in handing the experimental data. It certainly needs to be confirmed whether the large mass difference really disappears.

2 The BELLE and FOCUS experiments

The BELLE collaboration studied $\tau^-\to K^*(892)^-\nu_\tau\to K_S\pi^-\nu_\tau$ and for the first time measured the $K^*(892)^-$ mass and width in τ decay[5].

After getting the $K_S\pi^-$ invariant mass, they fitted it with Eq. (2) of Ref. [5] for the $K_S\pi^-$ mass between 640 and 1780 MeV/c^2. The differential width for $\tau^-\to K^*(892)^-\nu_\tau\to K_S\pi^-\nu_\tau$ is

$$\frac{d\Gamma}{dm}=\frac{1}{m^2}\left(1-\frac{m^2}{m_\tau^2}\right)\left(1+2\frac{m^2}{m_\tau^2}\right)\times (P(m))^3|BW_{K^*(892)}(m)|^2\,, \tag{5}$$

where $P(m)$ is the momentum of K_S in the $K_S\pi^-$ rest frame with the form

$$P(m)=\frac{1}{2m}\sqrt{[m^2-(m_K+m_\pi)^2][m^2-(m_K-m_\pi)^2]}\,, \tag{6}$$

and

$$BW_{K^*(892)}(m)=\frac{M_0^2}{m^2-M_0^2+im\Gamma(m)}\,, \tag{7}$$

where

$$\Gamma(m)=\Gamma_0\frac{M_0^2}{m^2}\left(\frac{P(m)}{P(M_0)}\right)^3. \tag{8}$$

Here Γ_0 is the $K^*(892)$ width at $m=M_0$.

So in this experiment, the formula used to describe $K^*(892)^-$ decay is

$$\frac{d\Gamma}{dm}=(P(m))^3\left|\frac{M_0^2}{m^2-M_0^2+im\Gamma(m)}\right|^2. \tag{9}$$

Very recently, the BELLE collaboration gave a new report on $K^*(892)^0$ parameters from the study of $\tau^-\to K^*(892)^0K^-\nu_\tau\to K^+\pi^-K^-\nu_\tau$. They fitted the $K^+\pi^-$ mass spectrum with Eq. (2) of Ref. [6] in the range of about 650 to 1200 MeV/c^2. The decay formula for the $K^*(892)^0$ has the form

$$\frac{d\Gamma}{dm}\propto\left|\frac{M_0\Gamma(m)}{m^2-M_0^2-iM_0\Gamma(m)}\right|^2, \tag{10}$$

and

$$\Gamma(m)=\Gamma_0\left(\frac{P(m)}{P(M_0)}\right)^3\frac{M_0}{m}\frac{1+r_0^2(P(M_0))^2}{1+r_0^2(P(m))^2}\,. \tag{11}$$

To see the difference caused by the model difference, we generate the $K^*(892)^0$ mass spectrum of this BELLE experiment with Eqs. (10), (11) and parameters $M_{K^{*0}} = 895.10$ MeV/c^2 , $\Gamma_{K^{*0}} = 47.23$ MeV/c^2 and $r_0 = 3.53$ (GeV/c)$^{-1}$. Then we fit it with the BELLE $K^*(892)^-$ parametrization of Eq. (9) in the range 650 MeV/c^2 to 1200 MeV/c^2 and find the mass to be 896.46 MeV/c^2 and the width to be 45.38 MeV/c^2. The mass becomes 1.36 MeV/c^2 greater and the width becomes 1.85 MeV/c^2 smaller than the initial values (see Fig. 1).

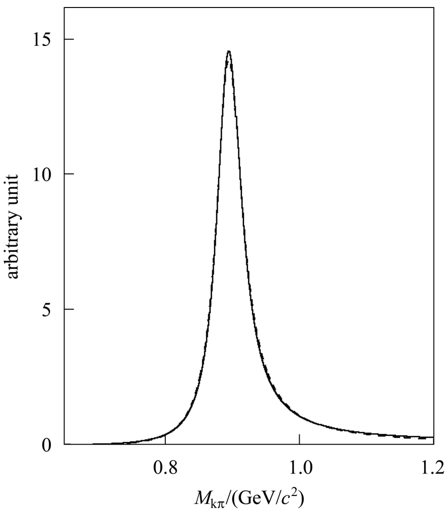

Fig. 1. Refit of the generated $K^*(892)^0$ mass distribution of the BELLE experiment with the BELLE $K^*(892)^-$ parametrization of Eq. (9) in the range 650 MeV/c^2 to 1200 MeV/c^2. The dashed spectrum is the generated $K^*(892)^0$ spectrum of BELLE, and the solid one is the fitting spectrum with the BELLE $K^*(892)^-$ model.

The FOCUS collaboration analyzed $D^+ \rightarrow K^*(892)^0\mu^+\nu \rightarrow K^-\pi^+\mu^+\nu$ decay and reported the mass and width of $K^*(892)^0$[7]. They fitted the $K^-\pi^+$ invariant mass spectrum between 650 to 1500 MeV/c^2 with Eq. (1) of Ref. [7]. We can see that they used $A_{J,\mathrm{R}}$ times the phase space factor P to fit the $K^*(892)$ decay spectrum. $A_{J,\mathrm{R}}$ is the amplitude of a resonance with angular momentum J, and

$$A_{J,\mathrm{R}} = \frac{M_0\Gamma_0}{m^2 - M_0^2 + \mathrm{i}M_0\Gamma(m)}\mathcal{F}_{J,m}\,, \qquad (12)$$

where

$$\Gamma(m) = \Gamma_0\mathcal{F}_J^2\frac{P(m)}{P(M_0)}\frac{M_0}{m}\,, \qquad (13)$$

and

$$\mathcal{F}_1 = \frac{P(m)}{P(M_0)}\frac{B(P(m))}{B(P(M_0))}\,. \qquad (14)$$

Here B is the Blatt-Weisskopf factor with $B = 1/\sqrt{1+r_0^2(P(m))^2}$.

So the formula used to describe $K^*(892)^0$ decay in the FOCUS experiment has the form

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}m} \propto \left|\frac{m_0\Gamma_0\dfrac{P(m)}{P(M_0)}\dfrac{\sqrt{1+r_0^2(P(M_0))^2}}{\sqrt{1+r_0^2(P(m))^2}}}{m_{K\pi}^2 - M_0^2 + \mathrm{i}M_0\Gamma(m)}\right|^2 P(m)\,, \qquad (15)$$

with

$$\Gamma(m) = \Gamma_0\left(\frac{P(m)}{P(M_0)}\right)^3\frac{M_0}{m}\frac{1+r_0^2(P(M_0))^2}{1+r_0^2(P(m))^2}\,, \qquad (16)$$

In addition to the $K^*(892)$ resonance, the FOCUS collaboration also included a non-resonant scalar component in the fit of the $K\pi$ mass spectrum in the range 650 MeV/c^2 to 1500 MeV/c^2. For one resonance only, the Breit-Wigner function can not well describe the resonance spectrum in the range far from the peak. So we first compare the model difference excluding the region far from the peak. We generate the $K^*(892)$ mass spectrum with the FOCUS parametrization of Eqs. (15, 16) and parameters $M_0 = 895.41$ MeV/c^2, $\Gamma_0 = 47.79$ MeV/c^2, and $r_0 = 3.96$ (GeV/c)$^{-1}$. Then we fit the spectrum with the BELLE $K^*(892)^-$ parametrization of Eq. (9) in the range 650 MeV/c^2 to 1200 MeV/c^2, and obtain mass 894.38 MeV/c^2 and width 43.71 MeV/c^2 (see Fig. 2). The mass becomes 1.03 MeV/c^2 smaller and the width becomes 4.08 MeV/c^2 smaller than the initial values.

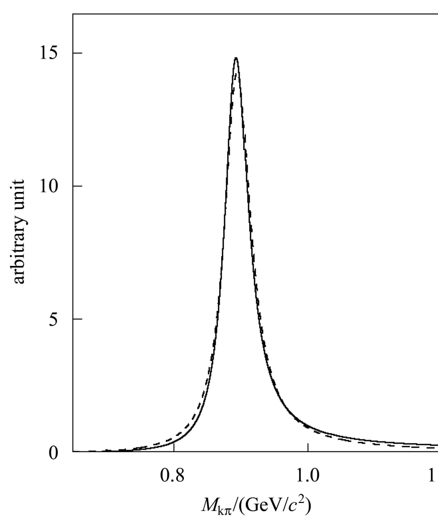

Fig. 2. Refit of the generated $K^*(892)^0$ mass distribution of the FOCUS experiment with the BELLE $K^*(892)^-$ parametrization of Eq. (9) in the range 650 MeV/c^2 to 1200 MeV/c^2. The dashed spectrum is the generated $K^*(892)^0$ spectrum of FOCUS, and the solid one is the fitting spectrum with the BELLE $K^*(892)^-$ model.

We now include the region for mass-greater than 1200 MeV/c^2 to see the effect of the fit range. We find that when the high mass value of the fit range increases, the refitted width decreases quickly but the refitted mass changes little. This means the spectrum difference in the high mass region affects the width a greater deal, but has little effect on the mass. If we fit in the range 650 MeV/c^2 to 1500 MeV/c^2, we find the mass of $K^*(892)^0$ to be 894.43 MeV/c^2 and the width to be 39.97 MeV/c^2 (see Fig. 3). When the low value of the fit range is 650 MeV/c^2 and the high value changes between 1200 MeV/c^2 and 1500 MeV/c^2, the refitted mass changes by less than 0.1 MeV/c^2 but the refitted width changes by more than 5 MeV/c^2. If we fit in the range 850 MeV/c^2 to 950 MeV/c^2 or smaller (the peak region), the mass and width become very similar to the initial values. The new values in the different fit ranges are listed in Table 1. We conclude that the parametrization models are not very different in the peak region, but could be very different when the mass is far from the peak.

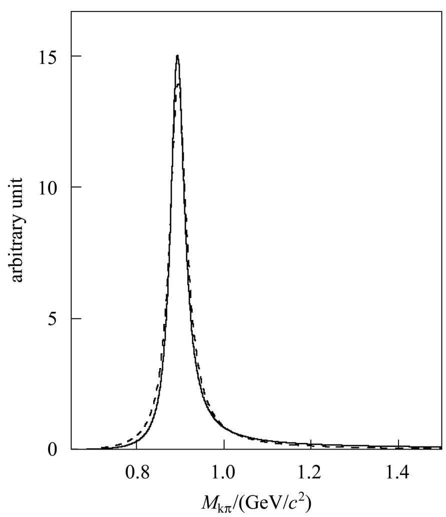

Fig. 3. Same as Fig. 2, but the fit range is from 650 MeV/c^2 to 1500 MeV/c^2.

Table 1. Refit of the FOCUS $K^*(892)^0$ spectrum with the BELLE $K^*(892)^-$ formula in different fit ranges. The initial parameters are $M_0 = 895.41$ MeV/c^2, $\Gamma_0 = 47.79$ MeV/c^2 and $r_0 = 3.96$ (GeV/c)$^{-1}$. The units of the values in the table are MeV/c^2.

range	refitted mass	refitted width
650—1500	894.43	39.97
650—1350	894.39	41.68
650—1200	894.38	43.71
650—1080	894.46	45.85
780—1080	894.52	45.50
850—950	895.30	47.81

To validate the procedure, we also generate the $K^*(892)^-$ decay spectrum of the BELLE experiment in the range 640 MeV/c^2 to 1780 MeV/c^2 with Eq. (9) and M_0 = 895.47 MeV/c^2 and Γ_0 = 47.79 MeV/c^2. The fit with BELLE $K^*(892)^-$ parametrization gives the same mass and width as the inputs.

So with the same parametrization, the mass splitting between neutral and charged $K^*(892)$ of BELLE is about 1 MeV/c^2, while the mass splitting between $K^*(892)^0$ of FOCUS and $K^*(892)^-$ of BELLE is about -1 MeV/c^2. After refitting in the range 650 MeV/c^2 to 1200 MeV/c^2, the $K^*(892)^0$ mass of FOCUS and BELLE has a difference of about 2 MeV/c^2 and the average value is 895.69±0.33 MeV/c^2. From the refitting results of the three measurements, the mass splitting becomes

$$\Delta m = 0.22 \pm 0.83 \text{ MeV}/c^2 . \tag{17}$$

This can be compared with the initial mass splitting value of -0.26 ± 0.83 MeV/c^2. After refitting, the neutral and charged $K^*(892)$ masses have bigger differences than the initial values. But the average mass splitting is still consistent with zero within errors and inconsistent with the previous theoretical and experimental results.

3 The previous experiments

We now try to examine the $K^*(892)$ parameters reported by previous experiments. This is a hard task because some authors did not give clear formulas used in describing the $K^*(892)$ spectrum.

We find that some authors used the same kind of basic theoretical model[8] to describe the $K^*(892)$ spectrum, which is in fact equivalent to Eq. (3). According to Ref. [8], $K^*(892) \rightarrow K\pi$ can be described as

$$\frac{d\Gamma}{dm} \propto \frac{m\Gamma(m)}{(m^2-M_0^2)^2+M_0^2\Gamma^2(m)} , \tag{18}$$

where $\Gamma(m)$ in the numerator includes the phase space factor P and the P^2 factor for a vector decaying into a pair of pseudoscalars, and the different correcting factors are also included in the $\Gamma(m)$ factor. In Refs. [9—12]

$$\Gamma(m) = \Gamma_0\left(\frac{P(m)}{P(M_0)}\right)^3 \frac{2(P(M_0))^2}{(P(M_0))^2+(P(m))^2} , \tag{19}$$

in Ref. [13]

$$\Gamma(m) = \Gamma_0\left(\frac{P(m)}{P(M_0)}\right)^3 \frac{M_0}{m} , \tag{20}$$

and in Ref. [14]

$$\Gamma(m)=\Gamma_0\left(\frac{P(m)}{P(M_0)}\right)^3. \qquad (21)$$

For the other experiments, we can not obtain the formulas they have used, so we will not discuss them here. We regenerate the K*(892) decay spectra with the formulas and parameters obtained from the above papers, then refit them with the BELLE $K^*(892)^-$ formula Eq. (9) in the range 650 MeV/c^2 to 1200 MeV/c^2. The results are listed in Table 2 and Table 3.

Table 2. The initial and refitted results of $K^*(892)^\pm$ of the previous experiments. The units of the mass and width in the table are MeV/c^2. The errors are taken as the same as before.

experiment	initial value		refitted value	
	mass	width	mass	width
Ref. [9]	888±3	54±9	887.30	51.51
Ref. [9]	891±1	56±4	890.27	53.47
Ref. [13]	886.6±2.4	43.0±8.4	886.6	43.00
Ref. [10]	891.7±0.6	52.0±2.5	891.06	49.71
Ref. [11]	891.9±0.7	52.1±2.2	891.25	49.81

Table 3. The initial and refitted results of $K^*(892)^0$ of the previous experiments. The units of the mass and width in the table are MeV/c^2. The errors are taken as the same as before.

experiment	initial value		refitted value	
	mass	width	mass	width
Ref. [12]	894.52±0.63	59.81±2.29	893.75	57.26
Ref. [12]	894.63±0.76	62.6±2.81	893.81	59.92
Ref. [11]	897.1±0.7	50.6±2.5	896.51	48.58
Ref. [14]	894.7±1.4	44±5.5	895.14	45.21

After refitting, the mass changes are less than 1 MeV/c^2 and the width changes are much bigger. In order to confirm the effect of the fit range on the refitted results, we fit the $K^*(892)^-$ spectrum of Ref. [9] in different fit ranges. We find that for this model, the spectrum difference in the high mass region far from the peak again has little effect on the mass but has a much larger effect on the width. The results are listed in Table 4.

For these experiments, the refitted masses of $K^*(892)^0$ are obviously larger than those of $K^*(892)^\pm$ just like before, which is not consistent with the mass splitting from the BELLE and FOCUS refitted results. We average the new refitted results of the previous experiments obtained from the fit in the range 650 MeV/c^2 to 1200 MeV/c^2, the mass of $K^*(892)^\pm$ is 890.80±0.41 MeV/c^2 and that of $K^*(892)^0$ is 894.70±0.39 MeV/c^2. The mass splitting then becomes

$$M(K^*(892)^0)-M(K^*(892)^\pm)=3.90\pm0.57\ \mathrm{MeV}/c^2. \qquad (22)$$

The new K*(892) mass splitting of these previous experiments is consistent with the PDG2008 average values and is about 4 MeV/c^2 larger than the new mass splitting from the BELLE and FOCUS refitted results.

Table 4. Refit of the $K^*(892)^-$ spectrum of Ref. [9] with the BELLE $K^*(892)^-$ formula in different fit ranges. The initial parameters are $M_0=891.0$ MeV/c^2, $\Gamma_0=56.0$ MeV/c^2. The units of values in the table are MeV/c^2.

range	refitted mass	refitted width
650—1500	890.19	50.89
650—1350	890.22	52.07
650—1200	890.27	53.47
650—1080	890.39	54.92
780—1080	890.43	54.63
850—950	891.03	55.92

4 Discussion and conclusion

After refitting the K*(892) signals with the same model, the $K^*(892)^0$ mass of BELLE becomes about 1.4 MeV/c^2 larger and the $K^*(892)^0$ mass of FOCUS becomes about 1 MeV/c^2 smaller than the initial values. The two new $K^*(892)^0$ masses are consistent with the refitting $K^*(892)^0$ masses of the previous experiments. The new $K^*(892)^-$ mass of the BELLE experiment is still different from that of the previous $K^*(892)^\pm$ experiments by about 5 MeV/c^2. The new $K^*(892)^-$ mass of BELLE is about 1 MeV/c^2 smaller than the new $K^*(892)^0$ mass of BELLE and about 1 MeV/c^2 larger than that of FOCUS, so the new average Δm from these measurements is still very small. The new Δm value is smaller than the theoretical Δm_{QM} value given, so the Δm_{EM} value should be smaller than zero. This means that from the refitting results of the three new measurements and the theoretical Δm_{QM} values given, the EM-mass of neutral K*(892) should be smaller than that of the charged one, which is normal like other particles. But the refitted results of the previous experiments are still consistent with the previous experimental and theoretical results, with a Δm value of about 4 MeV/c^2. After refitting, the new Δm values from the BELLE and FOCUS measurements are still inconsistent with those from the previous experiments.

The mass and width of K*(892) depends on models. So when we compare the mass and width difference between different experiments, it is important to consider the model used to describe them. We should also be careful about the fit range because it may cause uncertainty of the parameters. In addition, we find that the background shapes for $K^*(892)$ in different experiments are very different. Fitting results can be affected by both the signal model and the background shape because fitting software needs to adjust between signal and background.

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