A narrow Feshbach resonance is a closed channel dominated resonance rather than an open channel dominated resonance as in the broad case, whose near-threshold scattering and bound states only exist over a small fraction of width near resonance. It usually has a nontrivial energy dependent collisional phase shift as well as a narrow resonance width, which makes the theoretical modeling and experimental observation become complex and difficult. But this also introduces many interesting and difference physics in comparison to the widely studied broad Feshbach resonance. For example, the atomic-dimer relaxation ratio of the broad Feshbach resonance in an ultracold $^6$Li Fermi gas is suppressed as $a^{3.33}$ for two-body s-wave scattering length $a > 0$ [15], which results in an stable atom and molecular mixture, while this inelastic process is predicted to be enhanced if the effective range of the s-wave scattering phase shift $r_{\text{eff}}$ is larger than $a$ [15].

The two lowest-energy hyperfine ground states mixture of $^6$Li ($|\uparrow\rangle$ and $|\downarrow\rangle$) has a narrow s-wave Feshbach resonance at 543.3 G, whose resonance width is estimated to be only 0.1 G and $r_{\text{eff}} = -71000\alpha_0$ of the interaction potential is larger than the interparticle separation $\alpha_0$. Thus, the three-body recombination is supposed to be strong. As our previous study shows that three-body recombination of $^6$Li through the narrow Feshbach resonance follows a van der Waals universal and has an asymmetric strength profile across the resonance [16]. In the Bardeen-Cooper-Schrieffer (BCS) side, the loss width is about $E_F/\mu_B$, where $E_F$ is the Fermi energy and $\mu_B$ is the Bohr magneton. Therefore, in an extreme low temperature, the three-body loss will be located in a very small magnetic field regime with strong strength. In a sense, a milligauss stability and millisecond speed of magnetic field are suggested.

In this letter, we propose to use the ultra narrow width feature of the three-body loss near the $^6$Li narrow Feshbach resonance to sense the magnetic field. This method is a straightforward way to characterize the experienced magnetic field of the ultracold atoms. By applying the sensitive magnetic field discriminator from the three-body loss in narrow Feshbach resonance, the magnetic field changing time constant is highly determined in our system. Then we use the fitted result to study the time evolution result of the atom loss in the Bose-Einstein condensate (BEC) side and find that the main collision mechanism is also the three-body recombination in the BEC side when the magnetic field is close to resonance. This is also the first experimental measurement.

We produce the ultracold Fermi gases in an optical dipole trap [16, 17]. After the gases is cooled to 0.15 $\mu$K, about $N(t = 0) = 32500$ atoms per spin is left. The experimental timing sequence of magnetic field is shown in Fig. 1. We sweep the magnetic field to a initial value $B_i = 570$ G, where is tested to be stable for two component Fermi gases [8, 10]. Then the magnetic field is jumped to the target value $B_f$, stay for a variable time $t$. After that it is jumped back to $B_i$ and do the atom number $N(t)$ detection. As a consequence of the induced eddy current in the metal of our cold atom apparatus, the time response of magnetic field at the atom place is slower than the response of the driving current in the coils, which introduce error for many magnetic field dependent measurements if we use the driving current to scale the actual magnetic field. Especially, in our narrow Feshbach resonance experiments, the stabilization of the magnetic field often required to be a part per million (ppm) level, which put forward higher requirements for the dynamic properties of the magnetic field. Fig. 1 presents the measured driven current of the coils and estimated magnetic field during a fast sweep. The result shows the driving current can reach 20 ppm in 5.4 ms, but a better resolution is needed to further characterize the experienced magnetic field.
current resolution is absent due to the measurement limited of the digital multimeter. Considering the induced eddy current, the slowed down magnetic field response can be expressed by a first-order step response model [18], which is expressed as

\[ B(t) = (B_i - B_f)e^{-\frac{t}{\tau}} + B_f \]  

(1)

Where \( \tau \) is the time constant. The expected value of \( \tau \) is zero in an ideal scenario, but in our system, its value is on the order of milliseconds.

![FIG. 1. Timing sequence of driving current in the coils (blue dots) and estimated bias magnetic field at the atom place (red curve). The driving current is measured by a 7.5 bit digital multimeter (Keithley DMM7510) with 0.1 power line cycles and auto-zero setup. The inner figure zooms in the current dynamic at the turning point. The real magnetic field is calculated from Eq. (1) with the measured \( \tau = 5 \) ms, \( B_i = 570.9913 \) G, and \( B_f = 543.2735 \) G. In a typical three-body loss measurement sequence, the magnetic field starts from \( B_i \), then jumps to \( B_f \) and stay there for a variable time \( t \), after that jumps back to \( B_i \) to do atomic detection.](image1)

Three-body recombination at the BCS regime is measured. Its magnetic dependent properties can be described by [16]

\[ L_3(B) = \frac{3\hbar^3 K_{ad}}{(\pi m k_B T)^{3/2}} \exp\left[-\frac{2\mu_B (B - B_0)}{k_B T}\right] \]  

(2)

where \( K_{ad} \) is the atom-dimer relaxation rate, \( B_0 \) is the resonant magnetic field, \( h \) is the Planck constant and \( k_B \) is the Boltzmann constant. Accounting the slow magnetic response, the three-body atom loss \( N(t) \) is modified to

\[
\frac{1}{N^2(t)} = \frac{1}{V^2} \int_0^t L_3(B(t))dt + \frac{1}{N^2(t = 0)}
\]  

(3)

Where \( V \) is the average volume of atom gas. It is very important that we find \( L_3 \) is not sensitive to the very beginning unstable magnetic field response. So we submit the time of each measurements with a large enough time span, like 80 ms in our experiment, then do the fitting and get \( L_3 \). Fig. 2 presents these processes. We need point out that although we derive \( L_3 \), we still lose some information at the very beginning, which prevent our to explore some rapid phenomena, such as molecular formations [21], atomic-molecular collision and molecular-molecular collision [3], etc. By fitting the time shifted \( 1/N^2(t) \) data, we can get the \( L_3 \). Fig. 3(a) shows the measured \( L_3(B) \) at the BCS regime, which follows the tendency described in Eq. 2 with a fitted \( K_{ad} = 4.00 \times 10^{-8} \) cm$^3$/s. Note that the \( 1/e \) width of \( L_3(B) \) is only 0.0023 G, which is a much smaller than the resonance width 0.1 G. We choose three different \( B_f \) values, and measured their \( N(t) \) respectively, as shown in Fig. 3(c). We manually fit \( N(t) \) with Eq. 3, get the time constant of actual magnetic field response \( \tau = 5 \) ms. In this way, the actual magnetic field need about 54 ms to reach 1 ppm range, which also indicates this delay effect should be considered in many rapid experiments. We further use this magnetic field response prediction the \( N(t) \) at the BEC side, as shown in Fig. 3(b, d). The results turn out they are also in good agreement with the theoretical calculation.

![FIG. 2. Typical time evolution of \( 1/N^2 \) with a three-body loss in our experiment. Red dots are the 80 ms time shifted data of black dots. If we use a linear function to fit the black dots, the fitted \( 1/N^2(t = 0) \) will become almost zero, which is because of the very beginning data are taken under an unstable magnetic field due to the induced eddy current. Instead, fitting the red dots will give the right \( L_3 \) and \( 1/N^2(t = 0) \).](image2)
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to fit the $L_3(B)$ as shown in Fig. 3(b). The reason is experiment data of $L_3(B)$ has a very narrow unitary regimes at the resonance point, which may have some connections with the narrow p-wave Feshbach resonance [19]. The fitted Gaussian width is about 3 mG, which is comparable with the width at the BCS side.

In summary, we use the narrow Feshbach resonance of $^6$Li Fermi gases to realize a precision measurement of the magnetic field near the resonance. Our method directly measures the magnetic field at the location of the atom cloud, eliminating the effects of induced eddy current and residual magnetic. According to the result, the magnetic field response shows a large delay in comparing with the driven current. This is a key factor to be considered in many experiments related to the narrow Feshbach resonance. We find that three-body recombination dominates the atom loss in both BEC and BCS regime of the resonance. In the degenerate temperature, the energy broadening of the resonance is small. The technique of eliminating the eddy current provides a way to precisely determine the magnetic field of the narrow Feshbach resonance, and will give other chances for the future studies.

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