Supplementary materials for "*Testing the Electron-phonon Coupling for the Superconductivity in Kagome Metal CsV_3Sb_5*"

Yigui Zhong[1†], Shaozhi Li[2†], Hongxiong Liu[3†], Yuyang Dong[1], Yosuke Arai[1], Haoxiang Li[2], Youguo Shi[3], Ziqiang Wang[4], Shik Shin[1,5], H. N. Lee[2], H. Miao[2,*], Takeshi Kondo[1,*], Kozo Okazaki[1,6,7,*]

[1]*Institute for Solid State Physics, The University of Tokyo, Kashiwa, Chiba 277-8581, Japan*

[2]*Material Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*

[3]*Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences, 100190, Beijing, China*

[4]*Department of Physics, Boston College, Chestnut Hill, Massachusetts 02467, USA*

[5]*Office of University Professor, The University of Tokyo, Kashiwa, Chiba 277-8581, Japan*

[6]*Material Innovation Research Center, The University of Tokyo, Kashiwa, Chiba 277-8561, Japan*

[7]*Trans-scale Quantum Science Institute, The University of Tokyo, Bunkyo, Tokyo 113-0033, Japan*

[*]*Corresponding author:* miaoh@ornl.gov, kondo1215@issp.u-tokyo.ac.jp, okazaki@issp.u-tokyo.ac.jp

[†]These authors contributed equally to this work.

The supplementary materials include following parts:

1. Kink dispersion over momentum space
2. Estimation of superconducting transition temperature from EPC
3. Kink dispersion and charge density wave gap in the δ band
4. Temperature dependence of the kinks on the α and β band

1. Kink dispersion over momentum space

To investigate the momentum dependence of the electron-phonon coupling (EPC), we took 8 cuts along the FS of α band and 9 cuts along the FS of β band as shown in Fig. S1c. The ARPES intensity plots of these cuts are shown in Fig. S1a and S1b. Through applying Lorentzian fits to the MDCs, the extracted band dispersions are summarized in Fig. S1d, e for the α bands and Fig. S1g, h for the β bands. The deviations of the band dispersions at higher binding energies (E_B) to the linear fits at lower E_B highlight the electronic kinks. The kink energies can be determined by the peak positions of the $\mathrm{Re}\Sigma(\omega)$ plots shown in Fig. S1f and S1i. Clearly, the energy of the kinks is momentum independent.

The λ_{dev} is obtained by a linear fit at an energy range smaller than E_B~12 meV. The fits to determine λ_{dev} presented in Fig. 2f and 3f are demonstrated as black lines in Fig. S1f and S1i.

2. Estimation of superconducting transition temperature from EPC

The superconducting transition temperature T_c is estimated based on McMillan's formula which applies in the strong-coupling regime[32]:

$$T_c = \frac{\theta_D}{1.45} \exp\left[-\frac{1.04(1+\lambda)}{\lambda-\mu^*(1+0.62\lambda)}\right] \qquad (1),$$

Here θ_D is the Debye temperature, λ and μ^* are dimensionless parameters which describe the strength of effective electron-electron attractive and screened-repulsive interactions, respectively. When $\lambda > \mu^*$, the superconductivity can happen.

The Debye temperature θ_D is the average frequency of the coupled phonon modes calculated from the Eliashberg function $\alpha^2F(\omega)$ according to Eqs. (2)-(3) in main text. The average frequencies for the α and β bands are ~18.5 meV and ~15.7 meV, respectively. We take the average value ~17.1 meV to calculate the T_c. Thus, θ_D equals to ~198 K. The parameter μ^* is assigned to be 0.12, which is a theoretically suggested value[21]. Based on the θ_D = 198 K and μ^* = 0.12, the λ=0.45 ~ 0.6 determined from the kinks in the electronic band structure gives a T_c from 0.8 K ~ 3 K. The upper limit is close to experimental T_c of CsV_3Sb_5 sample (Fig. S2).

3. Kink dispersion charge density wave gap in the δ band

Both β and δ bands are captured in the cuts marked in Fig S3a. The ARPES intensity plots along cut 1 and cut 2 are shown in Fig. S3b and S3c. The V $3d_{yz}$ orbital derived β bands are favored in intensity under *s*-polarized light while the V $3d_{x^2-y^2}$ orbital derived δ bands are favored in intensity under *p*-polarized light. As extracted band dispersions shown in Fig. S3d and ReΣ(ω) plots in Fig. S3e, the kinks at E_B~12 meV and 32 meV are also observed in the δ band.

By symmetrizing the EDCs at k_F shown in Fig. S3d, a charge density wave (CDW) gap, which manifests as a dip at E_F, opens in the δ bands but nearly absent in the β bands. The CDW gap becomes larger in δ band when approaching to M points, which makes the band flatter at E_F, as Fig. S3b and S3c showing. The formation of the CDW gap near E_F may reduce the contribution of the δ bands in the superconducting paring.

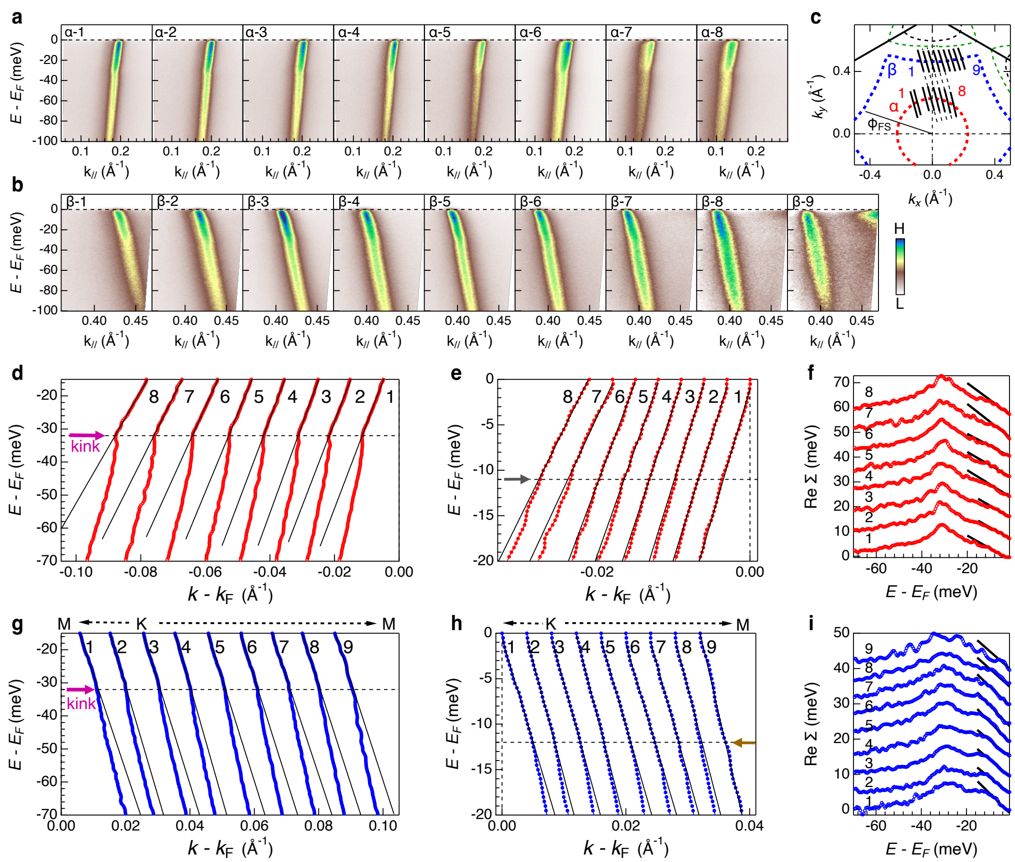

Fig. S1. The kink dispersion over momentum space. **a,b** ARPES intensity plots of the α and β bands taken along their FSs as shown in **c**. **d,e** Band dispersions of the α bands shown in binding energy range [15, 70] meV and [0, 20] meV, respectively. The black lines are the linear fits to band dispersions below the kinks. **f** ReΣ(ω) plots of the α bands. The black lines are the linear fits to determine the λ_{dev}. **g,h** Same with **d,e** but for the β bands. **i** Same with **f** but for but for the β bands.

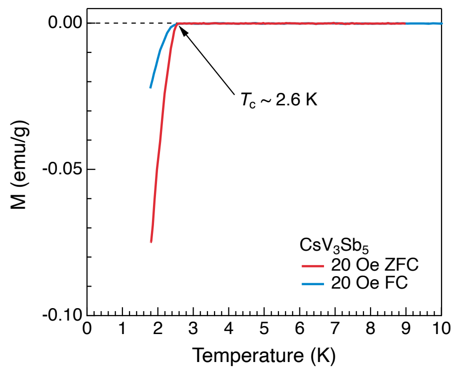

Fig. S2. Magnetism as function of temperature for CsV_3Sb_5 measured under 20 Oe magnetic field. The diamagnetism shows up below $T_c \sim 2.6$ K.

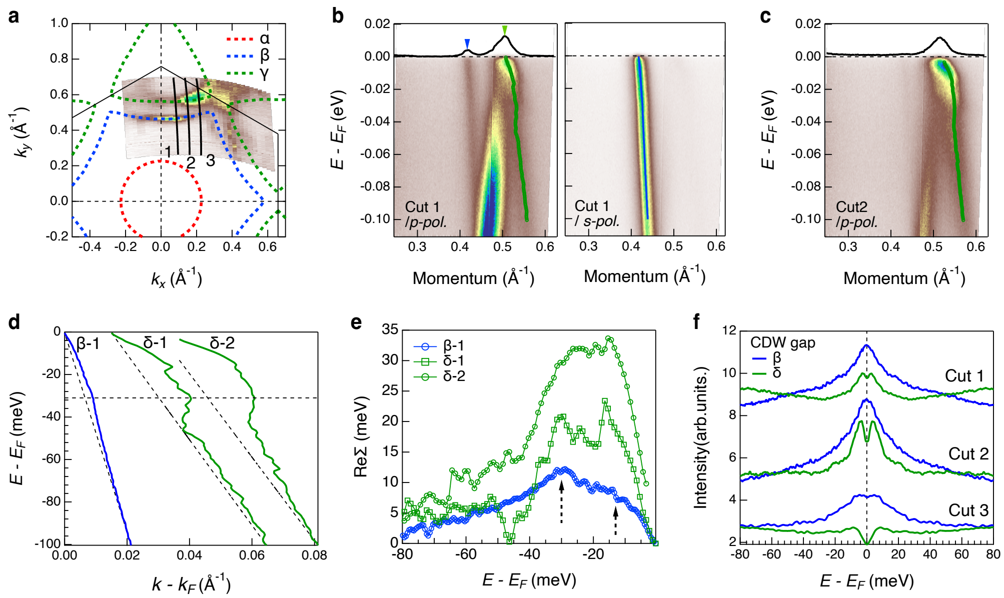

Fig. S3. The kink dispersion and CDW gap in the δ bands. **a** ARPES intensity integrated over $E_F \pm 10$ meV. The dashed lines represent the Fermi surface contours. **b,c** ARPES intensity plots of cut 1 and 2 marked in **a** measured with *s*- or *p*-polarized light. The black line in left panel of **b** is the MDCs at E_F which shows two peaks contributed from the β and δ bands. The green dotted lines are the dispersions derived from fits to the MDCs. **d** Extracted band dispersions of the β and δ bands in cut 1 and the δ band in cut 2. Bare bands are shown as black dashed liens. **e** ReΣ(ω) of the band dispersion presented in **d**. **f** Symmetrized EDCs at k_F of the β and δ bands along cut 1 to cut3 marked in **a**.

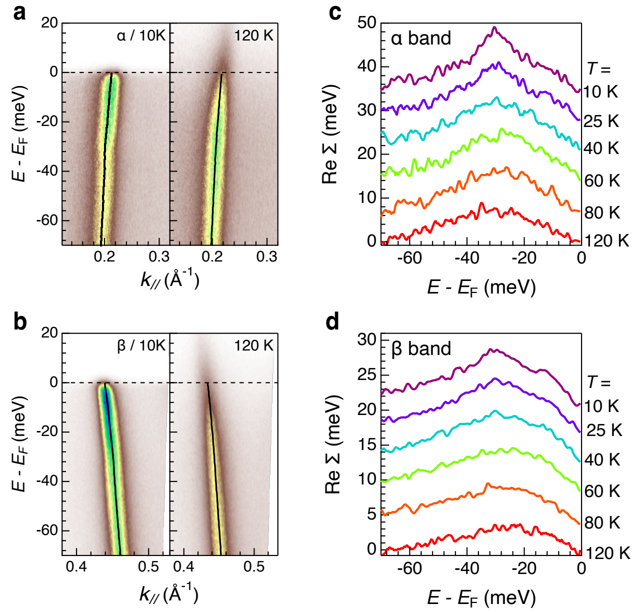

Fig. S4. Persistent kinks above CDW transition temperature at 94 K. **a,b** The ARPES intensity plots at T = 10K and 120K for the α and β bands, respectively. **c,d** ReΣ(ω) at different temperatures for the α and β bands, respectively.