Dual character of spin excitations in lightly Te-doped FeSe

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Abstract: Iron chalcogenide superconductors $FeSe_{1-x}Ch_x$ (Ch = S, Te) exhibit an unusual double-dome superconducting phase diagram, the microscopic origin of which remains unclear. Here, we use inelastic neutron scattering to probe spin excitations in single-crystalline $FeSe_{0.67}Te_{0.33}$, positioned at the superconducting transition temperature (T_c) minimum between the two domes. We identify two distinct spin excitation components separated by a crossover energy ($E_c \approx 30$ meV). Below E_c the spin excitations emanate from the stripe-type wave vector (1, 0), with their intensity strongly suppressed upon warming above the nematic transition at $T_s \approx 40$ K, revealing strong coupling between them. Above E_c the high energy excitations disperse more steeply and display little temperature dependence across T_s. Further warming from T_s to 300 K results in the gradual downward evolution of the high-energy spin excitations, reaching an incommensurate wave vector near (1, ± 0.3) at the low-energy limit. The combined energy- and temperature-dependent responses point to competition between stripe and incommensurate excitations, which can contribute to the reduced T_c near the valley composition; while Te substitution may simultaneously tune the electronic structure in ways that could coexist with, or reinforce, this competition. These findings illuminate the intricate interplay of multiple components of magnetic excitations in shaping T_c of iron chalcogenides.

Doping phase diagram and constant energy plots

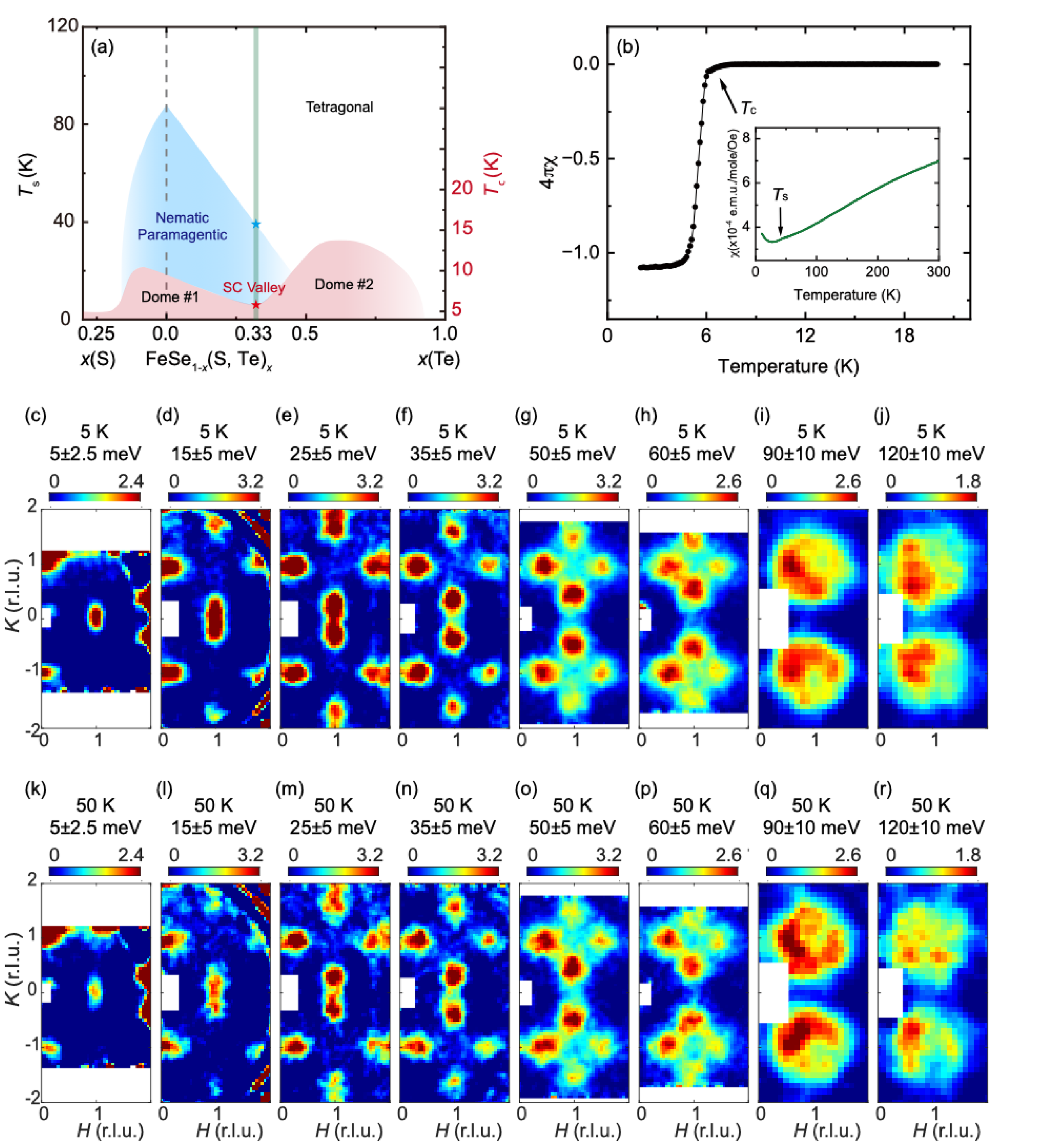

Fig. 1. (**a**, **b**) The doping range of our samples are indicated by the vertical orange bar in the phase diagram. DC magnetic susceptibility of our $FeSe_{0.67}Te_{0.33}$ single crystals. Zero-field-cooled (ZFC) magnetic susceptibility measured in a magnetic field of H=10 Oe. A sharp superconducting transition is observed at ~ 6 K. Magnetic susceptibility under a magnetic field of H = 70000 Oe. The kink at 40 K corresponds to the structural (nematic) phase transition. (**c**-**r**) Constant-energy schematic images of spin fluctuations in $FeSe_{0.67}Te_{0.33}$ projected onto the H-K plane at 5 K and 50 K.

Dispersions of stripe spin fluctuations

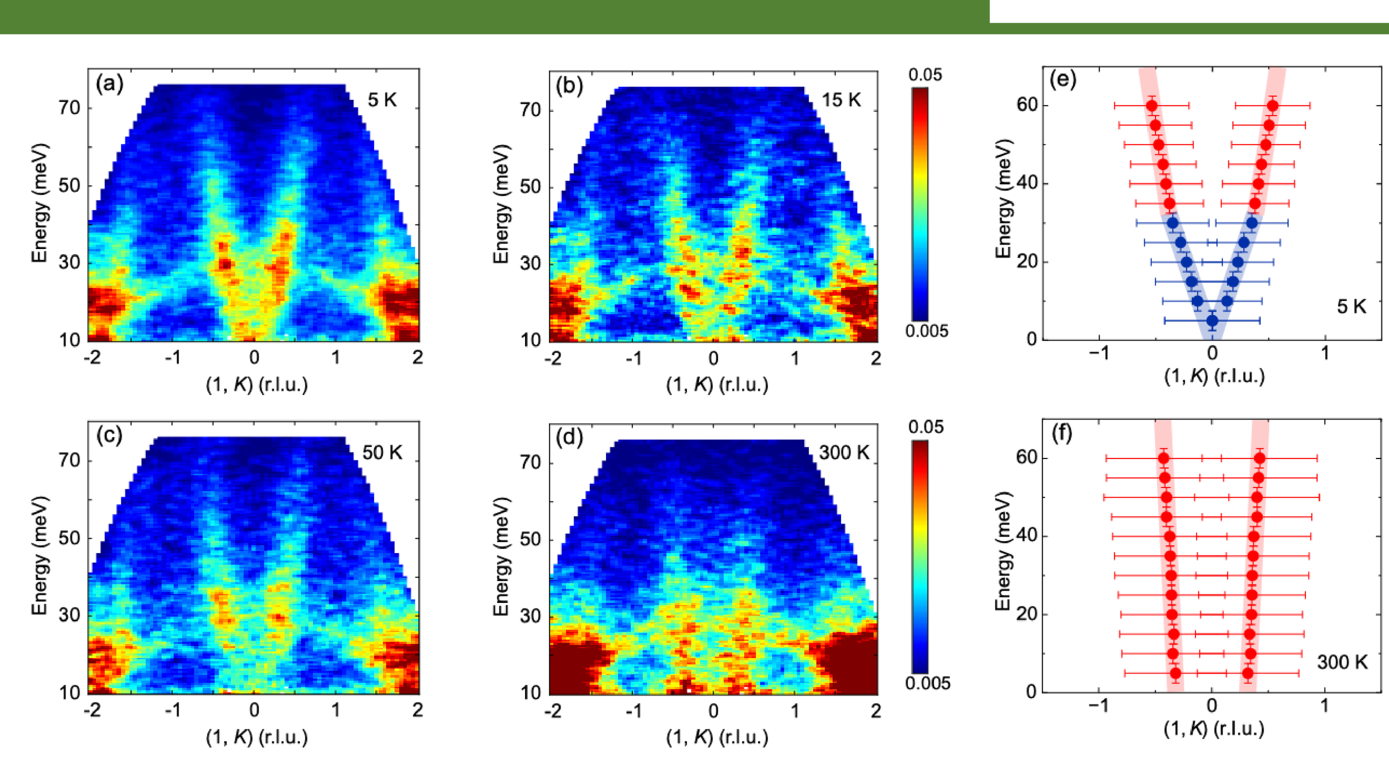

Fig. 2. (**a**-**d**) Dispersions of stripe spin fluctuations. (**e**, **f**) Extracted dispersion acquired from constant-energy cuts along the K direction at 5 K and 300 K, respectively.

1D-cut of the stripe spin fluctuations at 5 K, 50 K and 300 K

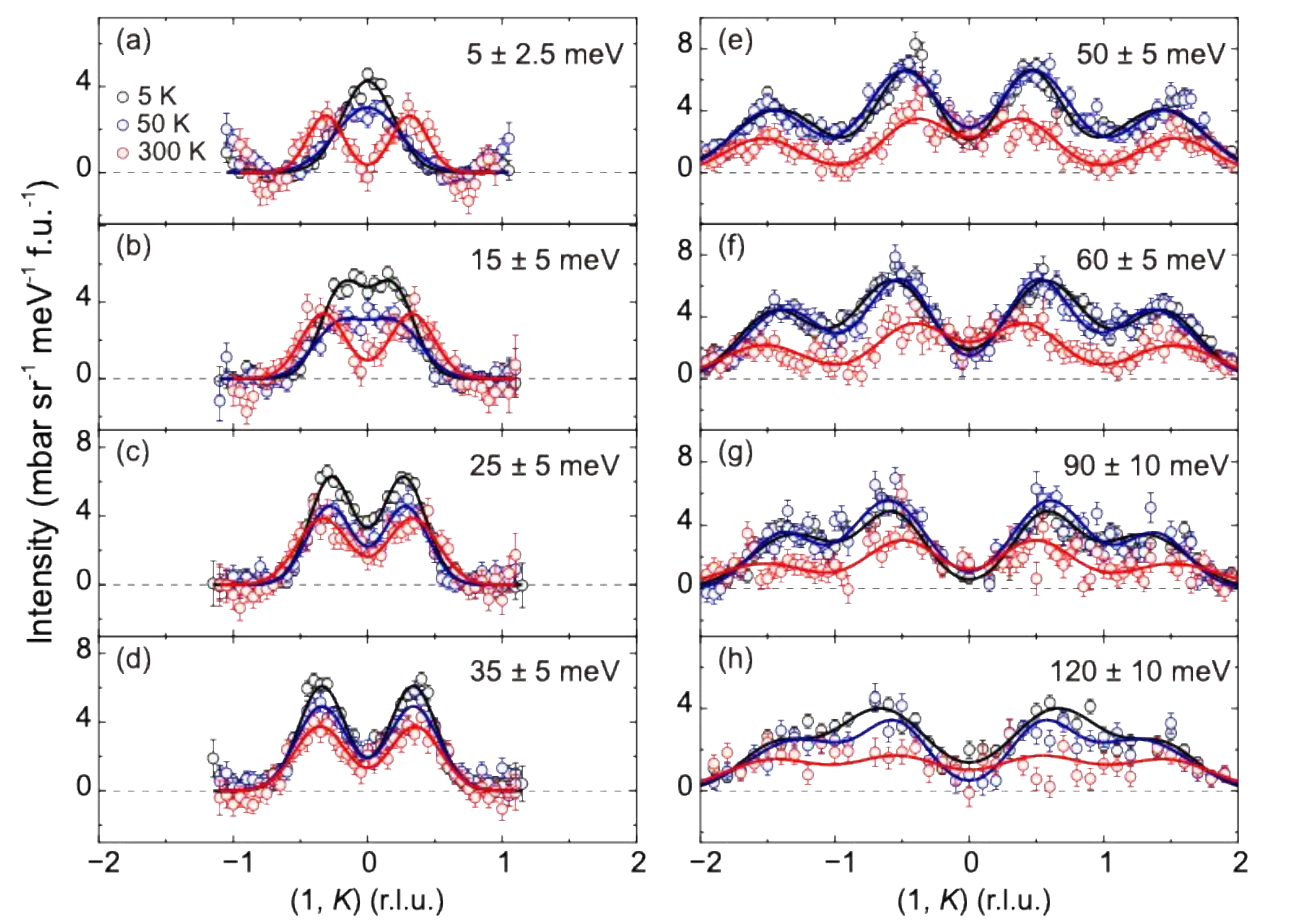

Fig. 3. (**a**) – (**h**) Constant-energy cuts through the stripe magnetic wavevectors along the transverse direction at 5K (black), 50 K (blue) and 300 K (red). . The peak positions are determined by fitting with Gaussian profiles convoluted with the instrumental resolution.

Temperature dependence and momentum integrated $\chi''(\omega)$

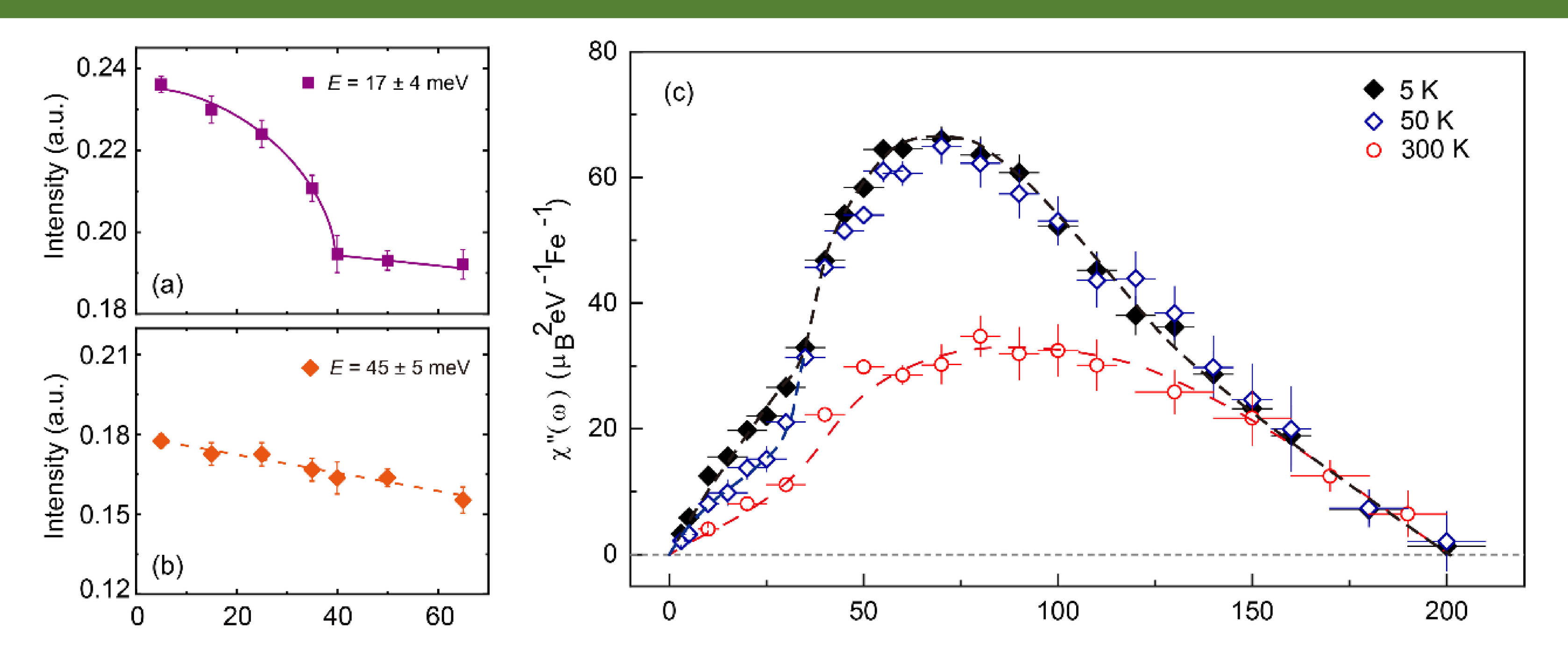

Fig. 4.(**a**, **b**) Low-energy spin excitations at 17 meV showed an order parameter-like behavior with nematic transition and high-energy spin excitations at 45 meV changed negligibly with increasing temperature. (**c**) Energy dependence of the local susceptibility $\chi''(\omega)$ at 5 K, 50K and 300K.

Conclusion

Our results reveal distinct dispersion and temperature-dependent behaviors in the low- and high-energy spin excitations, reflecting a dual nature of magnetic fluctuations. The unusual double-dome T_c phase diagram in $FeSe_{1-x}Ch_x$ can thus be interpreted as a macroscopic manifestation of the delicate interplay between spin fluctuations with different characters. Our findings highlight the critical influence of spin excitations, nematicity, and orbital-selective correlations on iron chalcogenides, offering valuable microscopic insights into the underlying mechanisms driving unconventional superconductivity.