Interactions in high-T_c cuprates: Large *d*-wave gap isotope shift and dispersive energy scales in (Pb-)Bi2212

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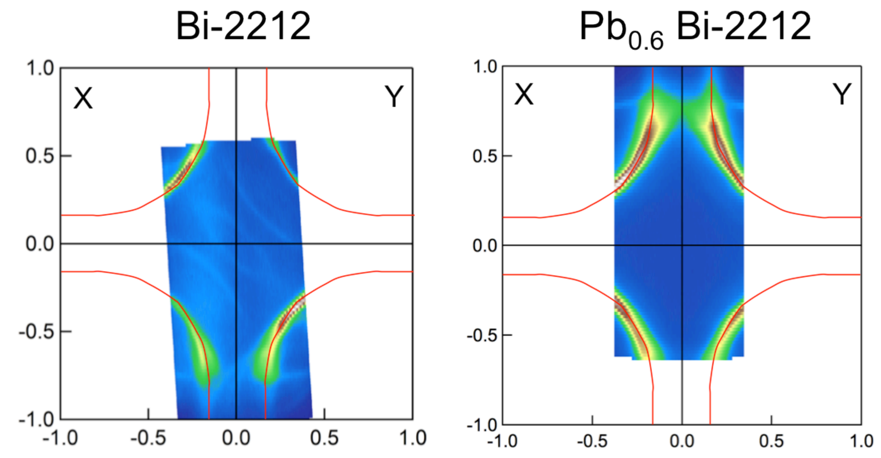
Abstract

Using low photon energy ARPES, we have performed detailed *k*-resolved studies of the *d*-wave superconducting gap in ^{16}O- and ^{18}O-substituted samples of the high-T_c superconductor $Bi_{1.4}Pb_{0.6}Sr_2CaCu_2O_{8+\delta}$ (Pb-Bi2212). At optimal doping, the gap size Δ_0 at the *d*-wave maximum decreases by about 4 meV upon ^{16}O → ^{18}O substitution – more than a 10% shift. These results are surprising, because the isotope effect is nominally strongly suppressed in the optimal-to-overdoped region of the cuprate phase diagram, with only a ~1% change in T_c at optimal doping. Combined with our other recent work investigating the so-called '70-meV' nodal 'kink', an intriguing picture of electron-boson interactions is emerging, suggesting key roles for both phonons and spin fluctuations.

Experimental

- 'Antinodal' ARPES: Pb-doped Bi2212, '(0,π)' orientation, $h\nu$ = 8.4 eV
- 'Nodal' ARPES: Bi2212 '(π,π)' orientation, $h\nu$ = 7 eV
- Isotopes annealed in identical conditions; T_c = 91/90 K (^{16}O/^{18}O); high substitution fraction confirmed by Raman spectroscopy

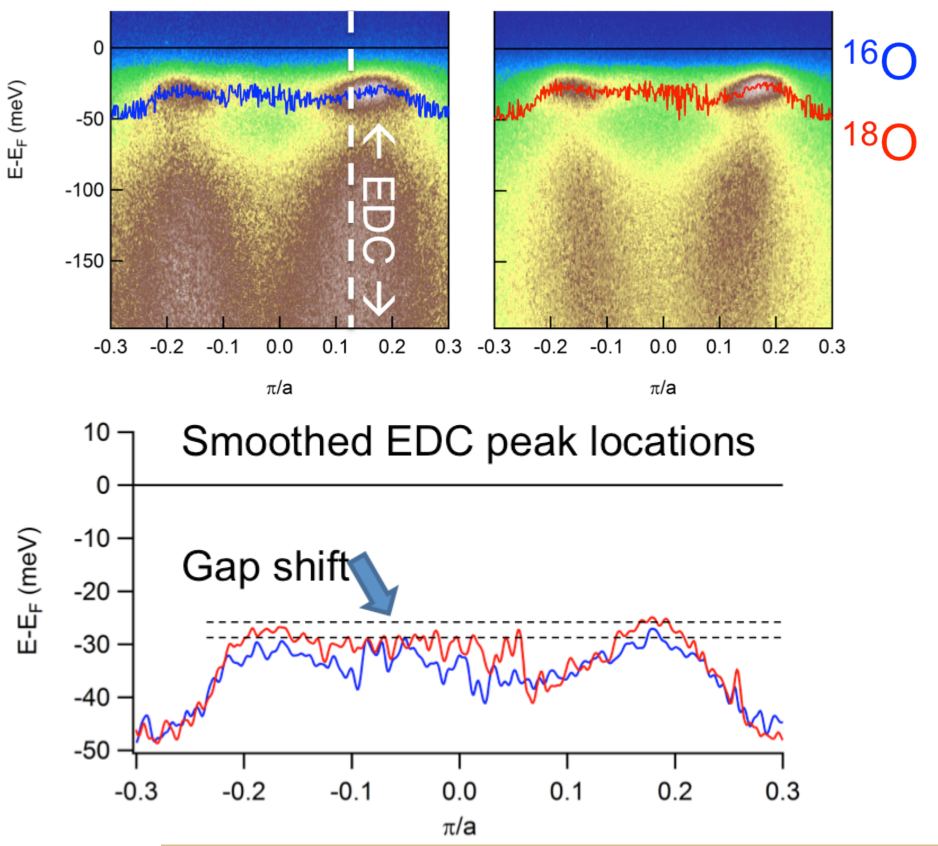
-Fermi surfaces showing reduced superstructure in Pb-Bi2212 for simplified analysis.
-Ultrahigh resolution, low back-ground spectra obtained by low-$h\nu$ ARPES.



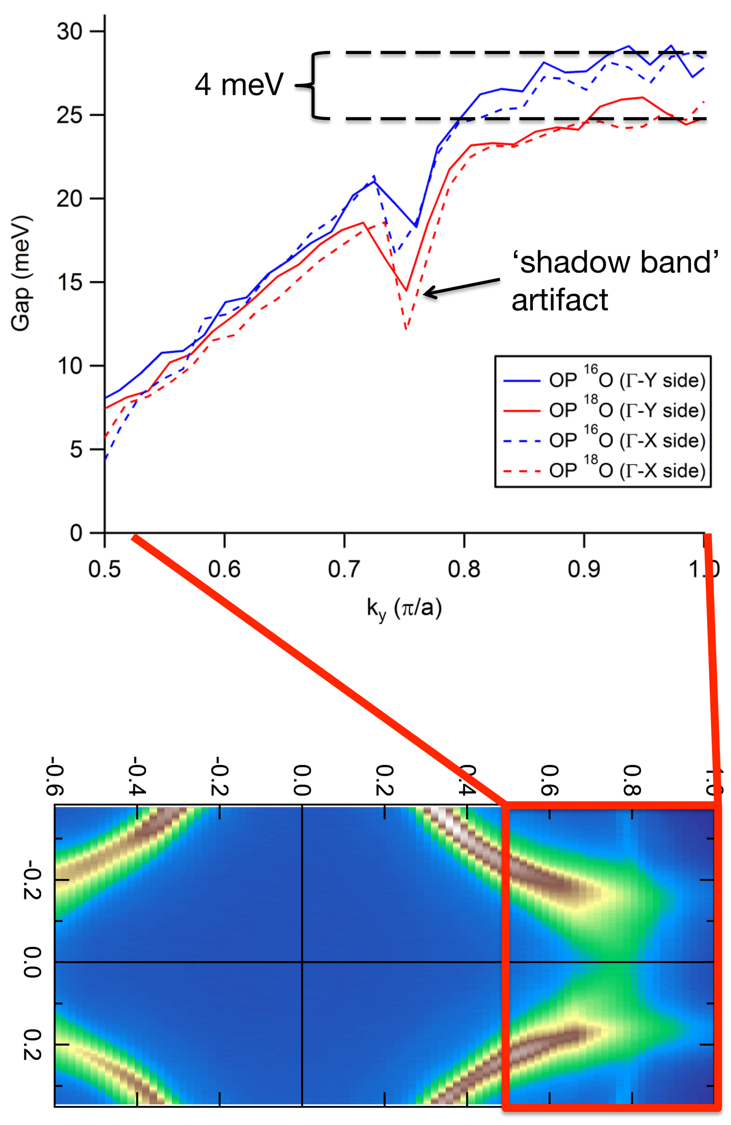
Large *d*-wave isotope shift

Antinodal spectra at (0,π)

- Data collected in (0,π) orientation
- Analysis of EDC peaks used for determining gap size
- ~4 meV isotope shift opens at antinode

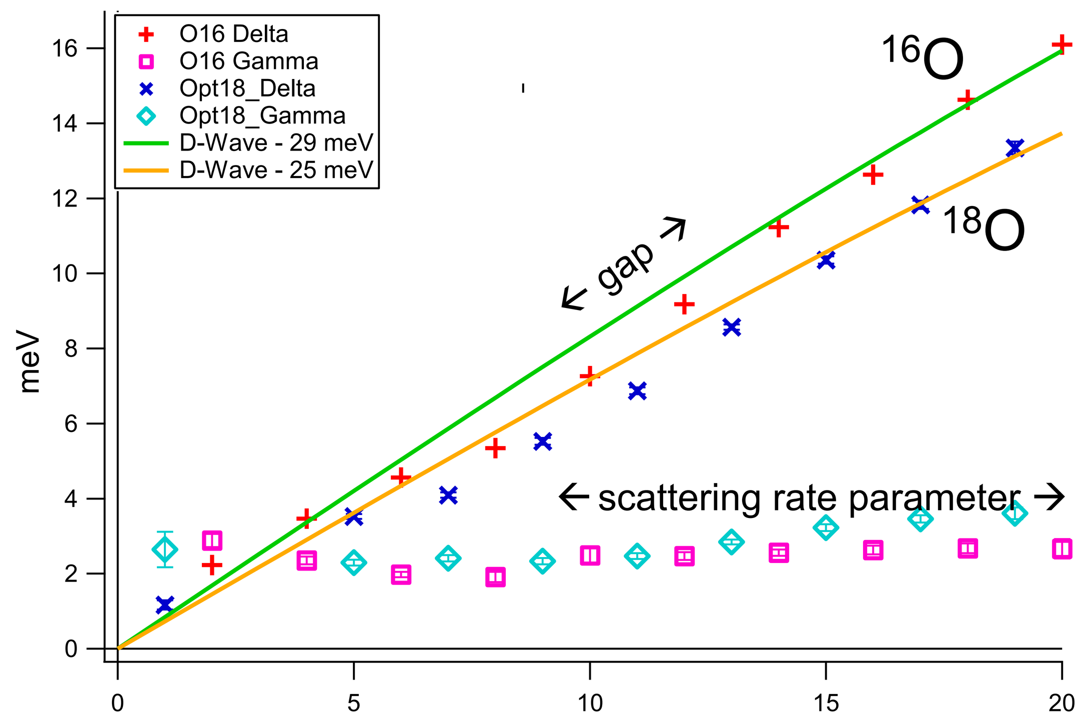


k dependence of gap shift

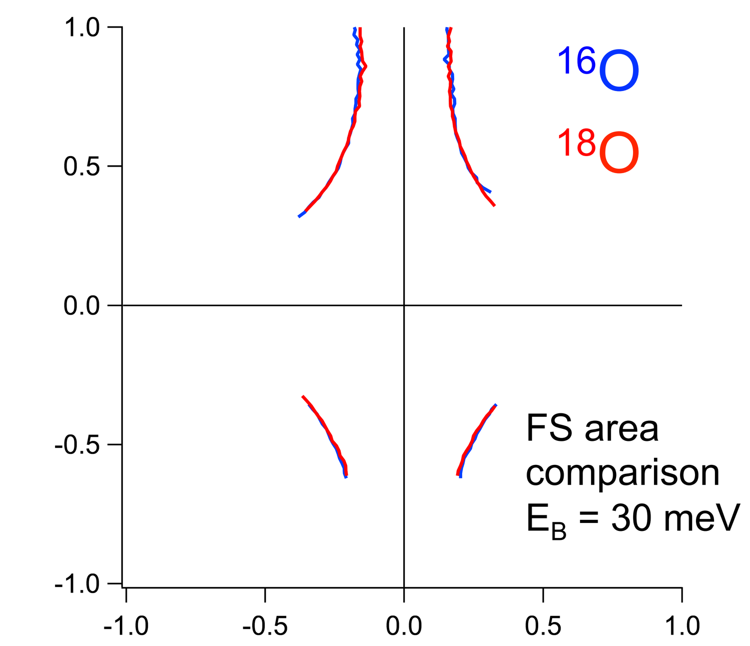


Extrapolated gap from nodal analysis finds same gap shift of ~4 meV

- Data collected in nodal (π,π) orientation
- Gap size analyzed by 'ARPES tunneling spectrum' (ATS) analysis [T. J. Reber et al., in preparation (2011).]
- Different analysis, cut orientation, and photon energy → same result of a projected ~4 meV gap shift at antinode



Doping and Fermi surface area

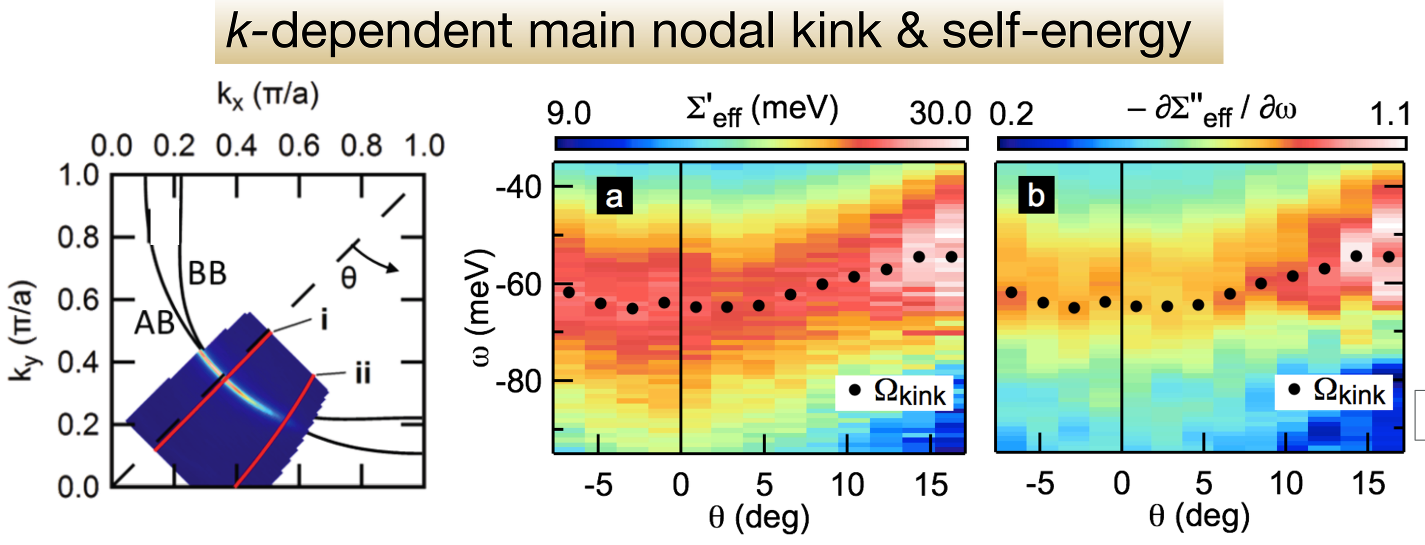


- Potential issue: Doping could vary between isotope samples, since ^{16}O/^{18}O mobility during annealing may be slightly different. Such an effect, if observed, could explain the isotope shift.
- However, current best estimate is that ^{16}O/^{18}O FS areas match better than ~1%.

Results confirmed from multiple beamtimes, photon energies & orientations for multiple sample pairs/batches!

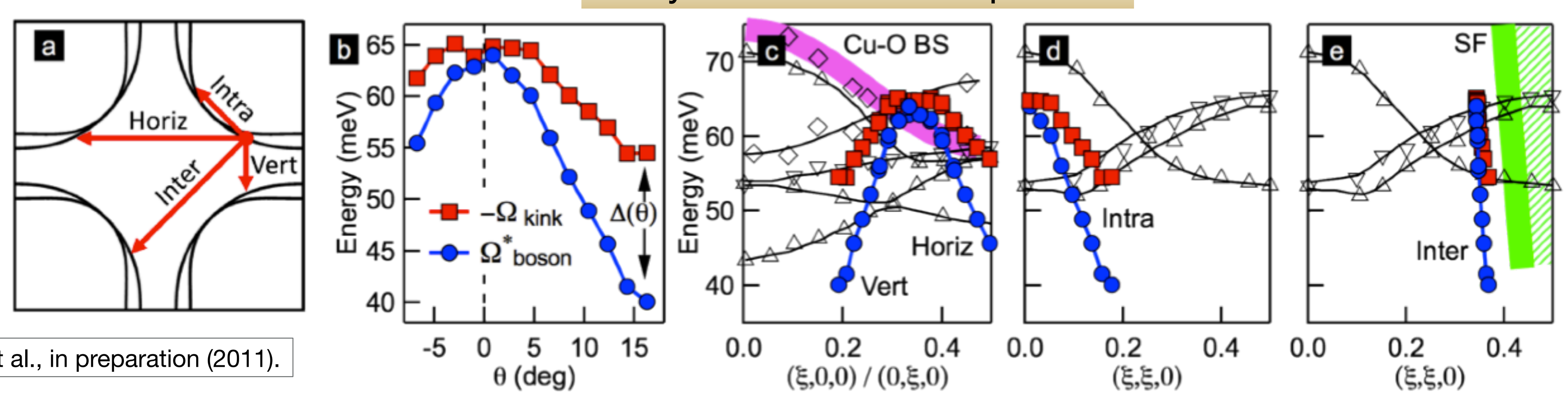
Nodal interactions: Dispersion of the '70-meV' kink

k-dependent main nodal kink & self-energy



- Detailed measurements of the effective self-energy due to the famous nodal '70-meV' dispersion kink in Bi2212.
- Peak location smoothly disperses, but intensity strongly jumps beyond ~10° away from the node.

Analysis of the kink dispersion

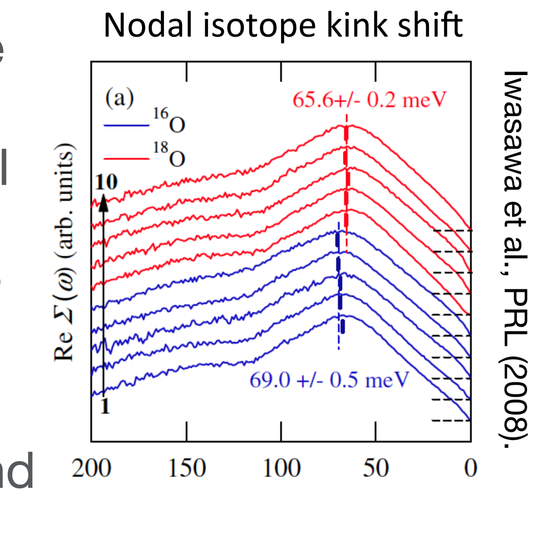


In an attempt to find a possible bosonic mode primarily responsible for the behavior of the nodal kink, we analyzed its dispersion in the scattering *q*-space connecting points on the Fermi surface along symmetry directions.

(a) Pure scattering vectors considered in our analysis. (b) Kink energy → boson energy conversion in our model, accounting for 'gap referencing'. (c)-(e) Comparing the model-extracted *q*-space dispersion to phonons (open symbols) and spin fluctuations (SF, green) along various symmetries.

Discussion: Evolving roles for phonons & spin fluctuations around the Fermi surface?

- Surprisingly large (~4 meV) isotope shift at the d-wave gap antinode
- Dispersion and k-dependent intensity of famous nodal '70-meV' kink appears more consistent with spin fluctuations than phonons, despite much evidence for phonons (e.g., ARPES → Iwasawa et al.; INS → 'soft' phonons)
- Total picture may signal key roles for both phonons and spin fluctuations, which evolve over the Fermi surface



Intensity of the self-energy

- Height of nodal self-energy peak as a function of the coupled boson energy extracted in our model for diagonal inter-pocket scattering.
- Result is compared to the SF 'resonance' peak seen in INS.

Results appear to favor spin fluctuations as the leading contribution to kink self-energy