ESRF	**Experiment title:** Electron momentum density in super- and normal fluid helium	**Experiment number:** HE-2261
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Report:

At the beamline ID15B we investigated He-4 in the superfluid and normal liquid states with Compton scattering spectroscopy.

As for its electronic structure, helium is the simplest possible system existing in nature. It only comprises 1s electrons and does not easily form chemical bonds with its surroundings. However, partly because exactly of that, the physics of helium can be very complicated [1]. For instance, superfluidity was predicted in helium-4 by Landau. Indeed, helium condenses to a liquid at 4.2 K, and turns into a superfluid at 2.17 K. In this state it can flow without friction. It becomes natural to ask what is the effect of superfluidity to the electrons of the He atoms. Do they feel the superfluid state, and if they do, how? We attempted to answer this question by measuring the Compton profiles of the electrons in superfluid and normal fluid He-4.

Compton spectroscopy measures the momentum density of the electrons, i.e. the $N(\mathbf{p}) = |\chi(\mathbf{p})|^{\mathbf{2}}$ where $\chi(\mathbf{p})$ is the electron wave function in momentum space (the Fourier transform of the $\psi(\mathbf{r})$, the wave function in real space). The experimentally determined quantity, the Compton profile $J(p_z)$, is the two-dimensional projection of the three-dimensional momentum density, $J(p_z) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} N(\mathbf{p})\ \mathrm{dp_x dp_y}$. It's direct connection with the electron wave function makes it a very appealing tool in condensed matter physics to study electronic properties [2].

The experiment was performed on ID15B. The radiation from the wiggler source was monochromatised to 56 keV and focused with a bent Si(311) monochromator. The spectrum of nearly backscattered (scattering angle 170°) inelastically scattered radiation was recorded using a multielement solid state detector with an average resolution of 350 eV in energy and about 0.4 atomic units in momentum space. We used a sorption cryogenerator capable of reaching temperatures around 1 K. The same cryogenerator has been used for other inelastic x-ray scattering experiments at the ESRF [3].

Fig. 1 shows the density of helium liquid as a function of temperature. Since different density can give rise to different amount of multiple scattering events, which may give differences to the spectra, the measurement was conducted at selected temperatures below and above the transition having exactly the same density (circles in Fig. 1 left panel). We observed the transition-induced change in the specific heat by scanning the temperature of the sample with a constant heating power (Fig. 1 middle panel) at $T = 2.15$ K (slight difference between literature value can be due to miscalibration of the sensor).

The Fig. 1 right panel shows the difference of the measured Compton profiles of superfluid and normal phase. We reached a statistical accuracy of about 0.02% at the Compton profile peak. It is indeed remarkable that no difference between Compton profiles could be observed even with this accuracy. It shows that the *electrons do not know whether the liquid is in superfluid or in normal state*. This is another manifestation of the validity of the Born-Oppenheimer approximation even in superfluid He-4.

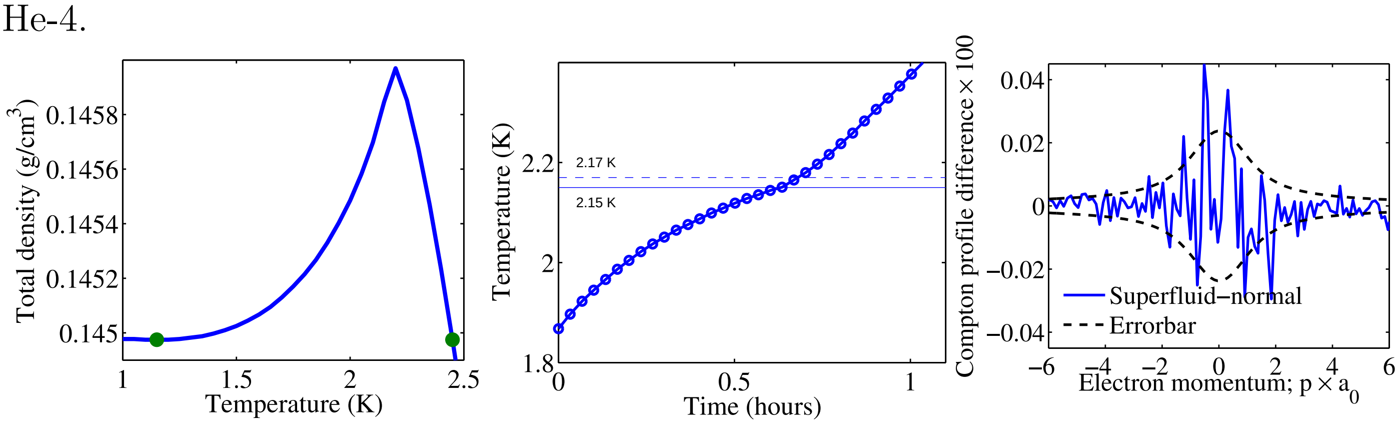

Figure 1. Left: Density of liquid helium as a function of temperature across the superfluidity transition. The circles mark the temperatures where the measurement was performed. Middle: We observed the lambda transition at $T = 2.15$ K evidenced by the change of specific heat. Right: Difference between Compton profiles of superfluid and normal liquid.

[1] K. R. Atkins, *Liquid helium*, Cambridge University Press, Cambridge (1959)

[2] M. J. Cooper, P. E. Mijnanrends, N. Shiotani, N. Sakai and A. Bansil, *X-ray Compton scattering*, Oxford University Press, Oxford (2004)

[3] F. Albergamo, R. Verbeni, S. Huotari, G. Vankó, and G. Monaco, *Zero Sound Mode in Normal Liquid ^{3}He*, Phys. Rev. Lett. 99, 205301 (2007)