Supplementary material to the article: Investigation of the superconducting gap in $PdTe_2$ by tunneling spectroscopy on side-junctions

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A. A MINIMAL MODEL FOR LOW RESISTIVITY N(I)S DEVICES

When current-biasing low resistivity devices, one often needs to send relatively high currents to reach voltages of the order of the gap magnitude. In the case of a disordered N-S interface, the critical current of the superconductor near the interface can be reached before $eV_{bias} \approx \Delta$ and the resulting dI/dV spectrum is no longer well described by the ballistic BTK model. In figure S1, a typical low resistance N(I)S interface is described as a metal side, which has a diffusive and a ballistic channel, in series with a superonducting side, which we assume to be ballistic in the normal state for this minimal model. The ballistic and diffusive contributions of the metal are modeled as W and $1 - W$ respectively, with W a fitting parameter between 0 and 1.

The I-V characteristic of a diffusive metal can in principle be easily described as a linear dependence $V_{dm} = IR_m$. This diffusive contribution causes heating at the interface as $T_{eff}^2 = T_{bath}^2 + V_{bias}^2/4L$, with L the Lorentz number [S1]. Because of the small temperature dependence $R(T)$ of metals at low temperatures, we assume the metal resistance to be constant. The ballistic I-V characteristic of the metal is also taken into account as $V_{bm} = IR_m$, but without the aforementioned heating effect. The I-V-characteristic of a superconductor can generally be described as $V_{SC} = sgn(I)\,\Re(\sqrt{I^2 - I_c^2})R_{SC}$, which holds below and above I_c.

For $I < I_c$, when the resistance contribution of the superconductor drops to zero, the resistance of the interface is entirely governed by the diffusive metal, which behaves again as $V_{dm} = IR_m$, and the ballistic metal which in this case is described by the BTK model: $V_{bm} = IR_{BTK}$ [S2]. The resulting I-V characteristics are shown in Figure S2(a).

The resulting total conductance spectrum will follow BTK behavior as long as $I < I_c$, damped by a parallel, diffusive contribution, and will jump at $I = I_c$ to saturate at a constant value that corresponds to the total metal and normal state $PdTe_2$ resistances. The effective temperature T_{eff} at the interface causes thermal smearing of the total I-V characteristic. In the BTK picture, this thermal smearing is taken into account as a broadening of the bias voltage. For the critical current features however, thermal smearing should be taken into account in the V-I curve by broadening the bias current $I_{Thermal} \sim V_{Thermal}/R_{total}$. This makes the amount of rounding of the critical current strongly dependent on the total resistance of the device. Figure S2(b) shows the total dI/dV conductance spectra, together with the conductance spectra of the isolated parts of the interface.

B. AN EXAMPLE OF A LOW RESISTANCE DEVICE THAT MIMICS P-WAVE BEHAVIOR

One of the lowest resistance N(I)S devices fabricated for this work, has a resistance of 11.3 Ω. The measured conductance specrum is shown in Figure S3 and exhibits a pronounced dome at zero bias, along with a parabolic background that is associated with Joule heating effects [S3]. This spectrum perfectly matches what one would expect for a helical-p superconductor with a high barrier (see Figure 2(h) of the main text).

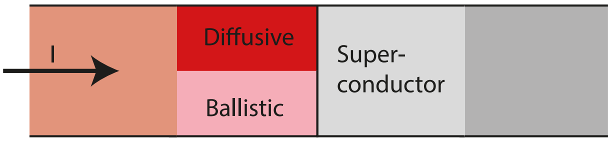

FIG. S1: A schematical illustration of the interface in this model. The left side represents the metal side, which is described by parallel ballistic and diffusive channels, and the right represents the superconductor side of the interface.

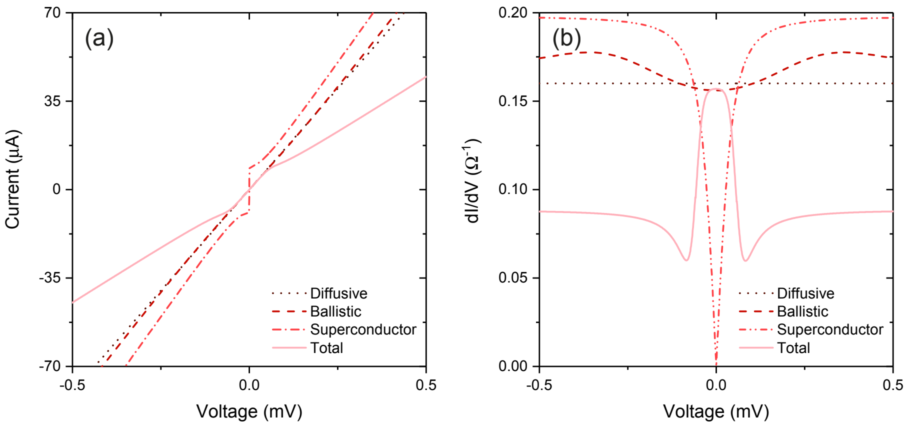

FIG. S2: (a) I-V characteristics of the separate parts of the interface, plotted against the voltage over this separate part. The total is modeled assuming a current bias setup. (b) The dI/dV conductance spectra corresponding to the I-V characteristics in panel a.

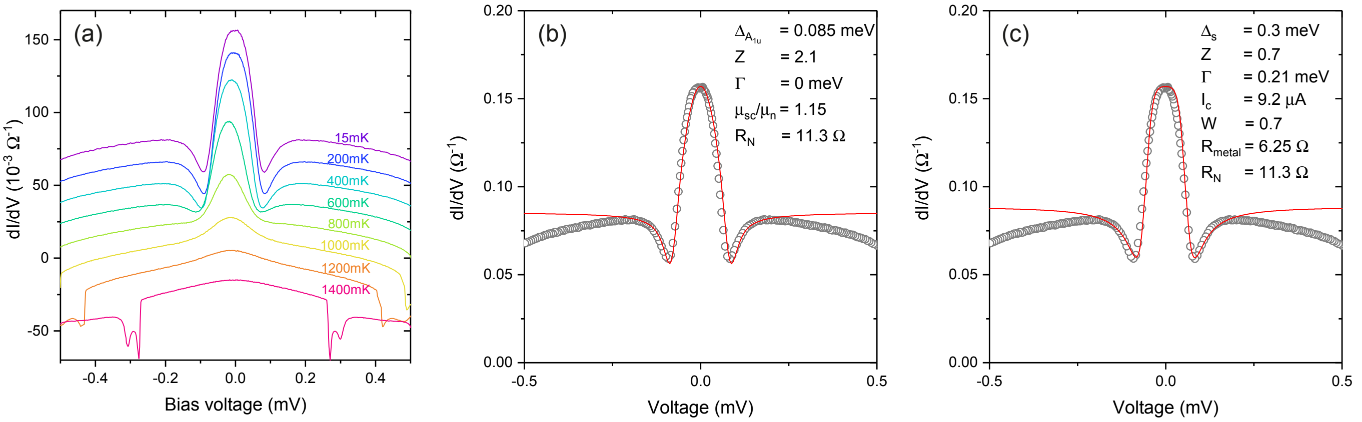

FIG. S3: (a) Temperature dependent dI/dV spectra for an $R_n = 11.3\ \Omega$ N(I)S device. The curves, except for 15 mK, are offset for clarity. (b) A 2D, A_{1u} BTK model fitted to the 15 mK data. (c) The s-wave + I_c model, discussed in section A, fitted to the 15 mK data.

Figure S3(b) shows the excellent correspondence between the measured data and a numerical model for an A_{1u} order parameter with $\Delta_{A_{1u}} = 0.085$ meV, a dimensionless barrier strength Z = 2.1, and a small chemical potential mismatch $\mu_{sc}/\mu_n = 1.15$. Despite the good fit to the data, the fitting parameters do not seem very appropriate for the device. Following the BCS model, the gap magnitude indicates $T_c \approx$560 mK, which does not match well to the temperature dependence in panel S3(a). The dimensionles barrier strength of Z = 2.1 is very high for a device with a normal state resistance of 11.3 Ω. Contrary to the other datasets presented in the main text, interpreted as p-wave this spectrum shows no sign of an additional s-wave order parameter, which is another indication that these measurements should not be interpreted as fully described by the BTK formalism.

In figure S3(c), the critical current model described in section A is fitted to the data. The fit parameters indicate 70% ballistic transport in the metal side of the barrier and a critical current $I_c = 9.2\ \mu$A. Instead of fitting the BTK parameters to the data, we assumed the same values as found from fits in the main text because the influence of the s-wave BTK contribution is rather small. This s-wave + I_c model matches just as well to the data as the p-wave model does, but in this case with much more realistic fit parameters.

The experimental data and theoretical fits presented in this section illustrate neatly the difficulties of studying the superconducting order parameter with a low resistance, point-contact like setup. To make hard statements about the nature of the superconducting order parameter, one preferably uses devices with thick barriers without pinholes, so that the resulting tunneling spectrum accurately corresponds to the density of states of the superconductor.

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