Hydrostatic pressure effect on the pseudogap in slightly doped $Y_{0.66}Pr_{0.34}Ba_2Cu_3O_{7-\delta}$ single crystals

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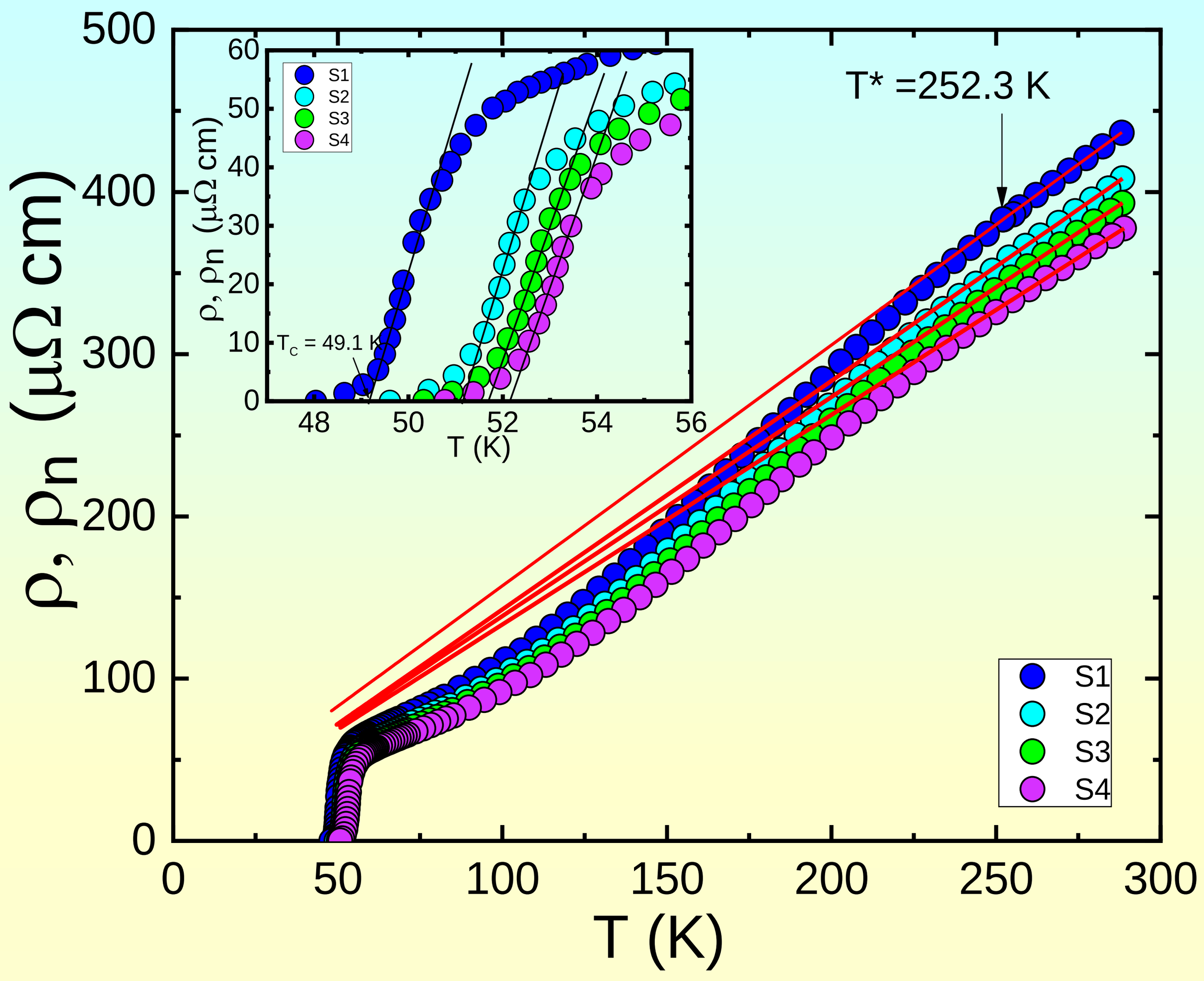
Introduction and motivation

The discovery of high-temperature superconductors (HTSCs) is undoubtedly one of the landmark events in modern solid state physics. However, despite the efforts of numerous scientific groups and an extraordinary number of publications on HTSCs, the mechanism of superconducting (SC) pairing, which makes it possible to obtain real Cooper pairs at T >> 100 K, is still not clear. The pseudogap (PG) state, which is opened in cuprate high-temperature superconductors (HTSCs) below the characteristic temperature T >> Tc, is one of the most mysterious and simultaneously interesting phenomena in modern solid state physics [1]. It is well established that in HTSCs, the PG is observed when the charge carrier concentration varies between slightly doped (SD) and optimally doped levels. Understanding the PG physics would definitely shed more light on the mechanism of superconducting pairing in HTSCs, which is also not fully clarified yet. The $YBa_2Cu_3O_{7-\delta}$ cuprate is believed to be the most reliable material for studying the PG [1], especially when high pressures is applied.*

Temperature dependences of the resistivity of on slightly doped $Y_{0.66}Pr_{0.34}Ba_2Cu_3O_{7-\delta}$ single crystal (Tc ≈ 49.1 K) at different pressure. The arrows designate T*.



$$\rho_N = \alpha \cdot T + \beta; \quad \alpha, \beta \text{ - const}$$

$$\sigma'(T) = 1/\rho(T) - 1/\rho_N(T)$$

S1=0

S2=0.372 GPa

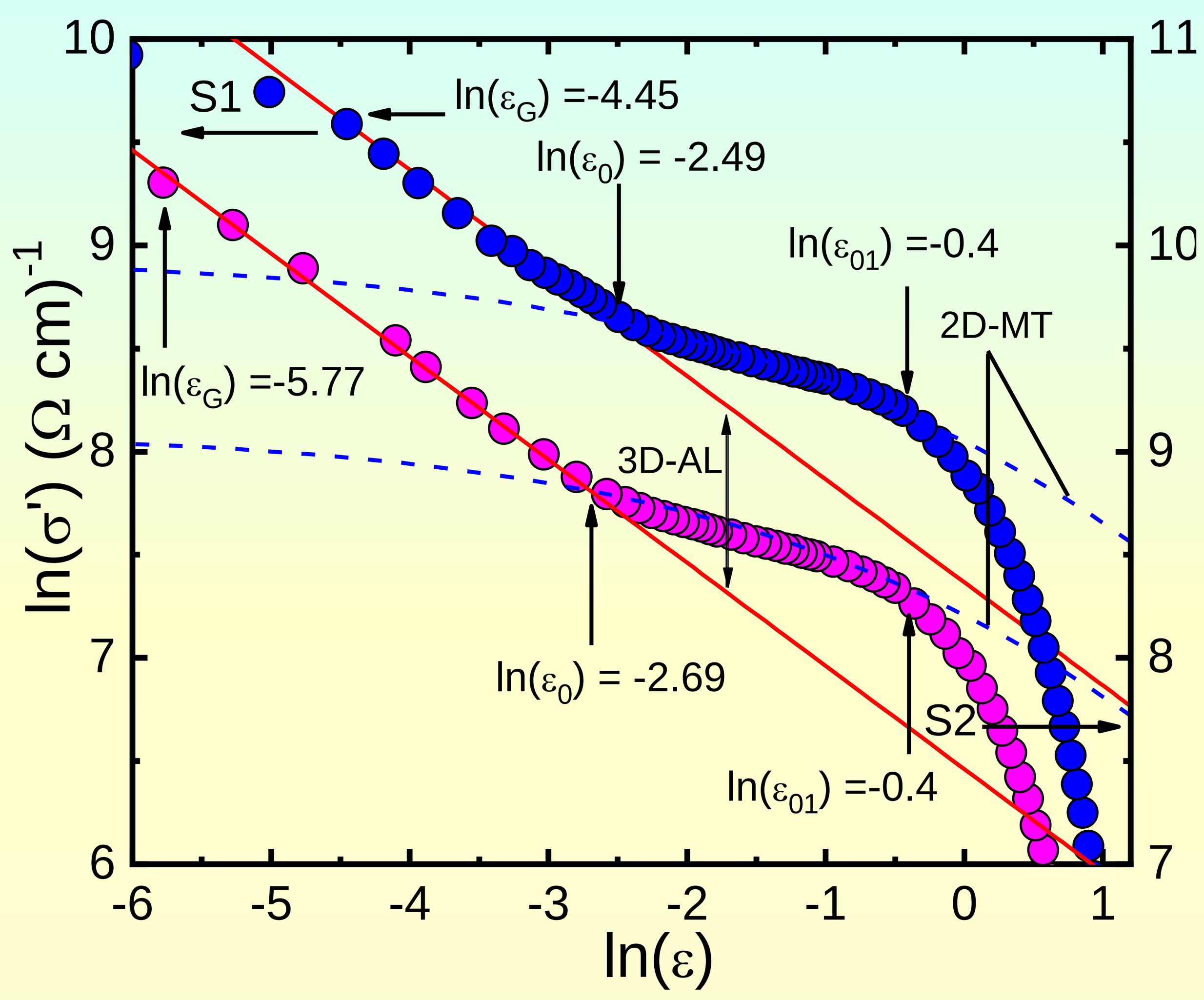
S3=0.653 GPa

S4=0.97 GPa

Table 1. ***Resistive and FLC parameters of $YPrBa_2Cu_3O_{7-\delta}$ single crystal at different pressure.***

GPa	$\rho(300K)$ $\mu\Omega(cm)$	$\rho(100K)$ $\mu\Omega(cm)$	T_c (K)	T_c^{mf} (K)	T_o (K)	T_{01} (K)	T_G (K)	d_{01} (A)	$\xi_c(0)$ (A)
0	436.43	105.3	49.1	50.13	54.3	82.4	50.7	4.1	3.36
0.372	408.26	98.91	51.1	52	56.1	84.2	52.3	4.2	3.28
0.653	393.18	95.5	51.5	52.6	56.6	89.5	52.8	3.69	3.08
0.97	377.53	91.72	51.9	53.0	57.0	85.3	53.2	3.73	3.05

Dependences of excess conductivity $\sigma'(T)$ versus the reduced temperature ε in double logarithmic scale for sample S1 (P=0) and S2 (P=0.97 GPa) in the range of SC fluctuations near Tc in comparison with 3D-AL (red straight lines) and 2D-MT (blue curves) fluctuation theories. All characteristic temperatures T_G, T_0 and are marked with arrows.



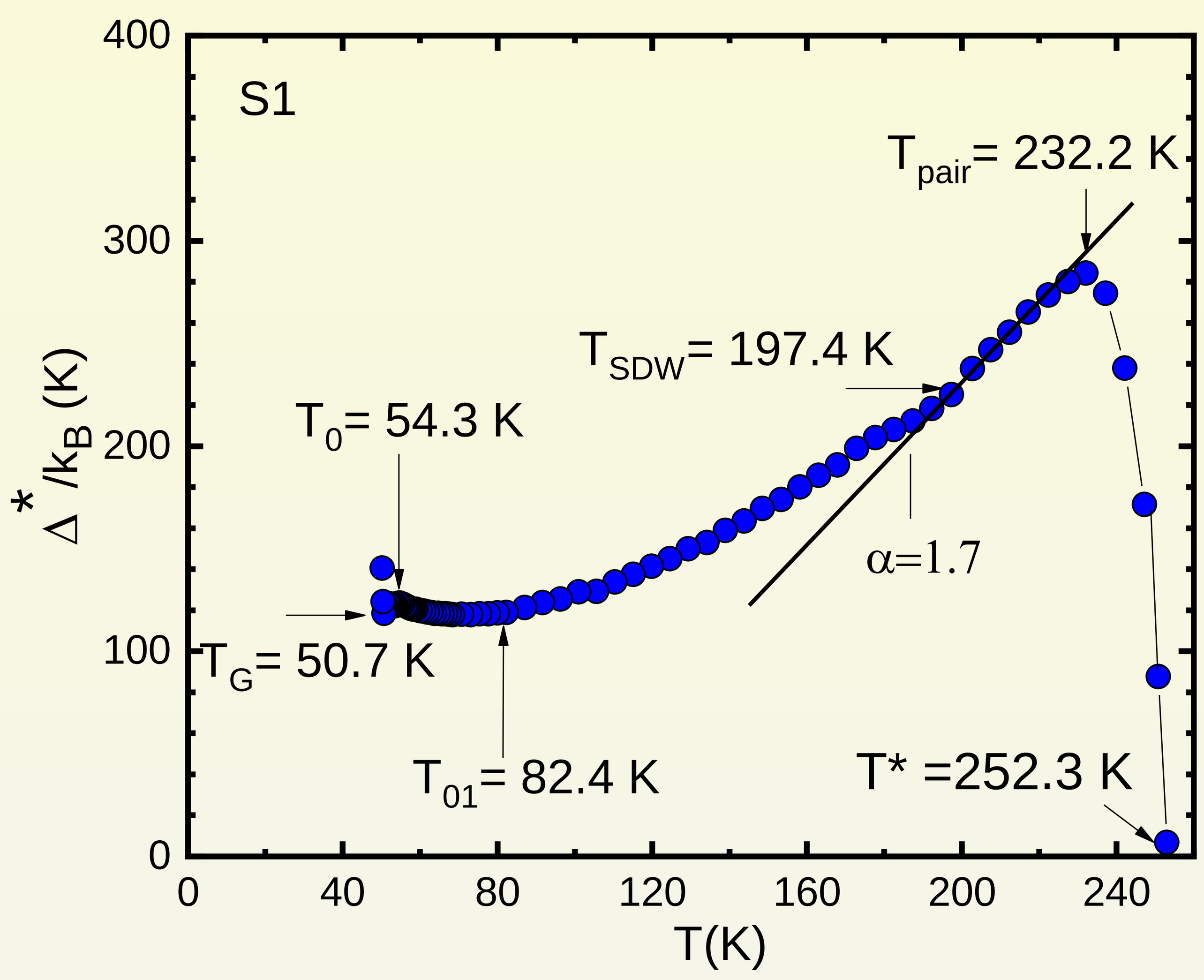
$$\sigma'_{AL} = \frac{e^2}{32\hbar\xi_c}\varepsilon^{-1/2}$$

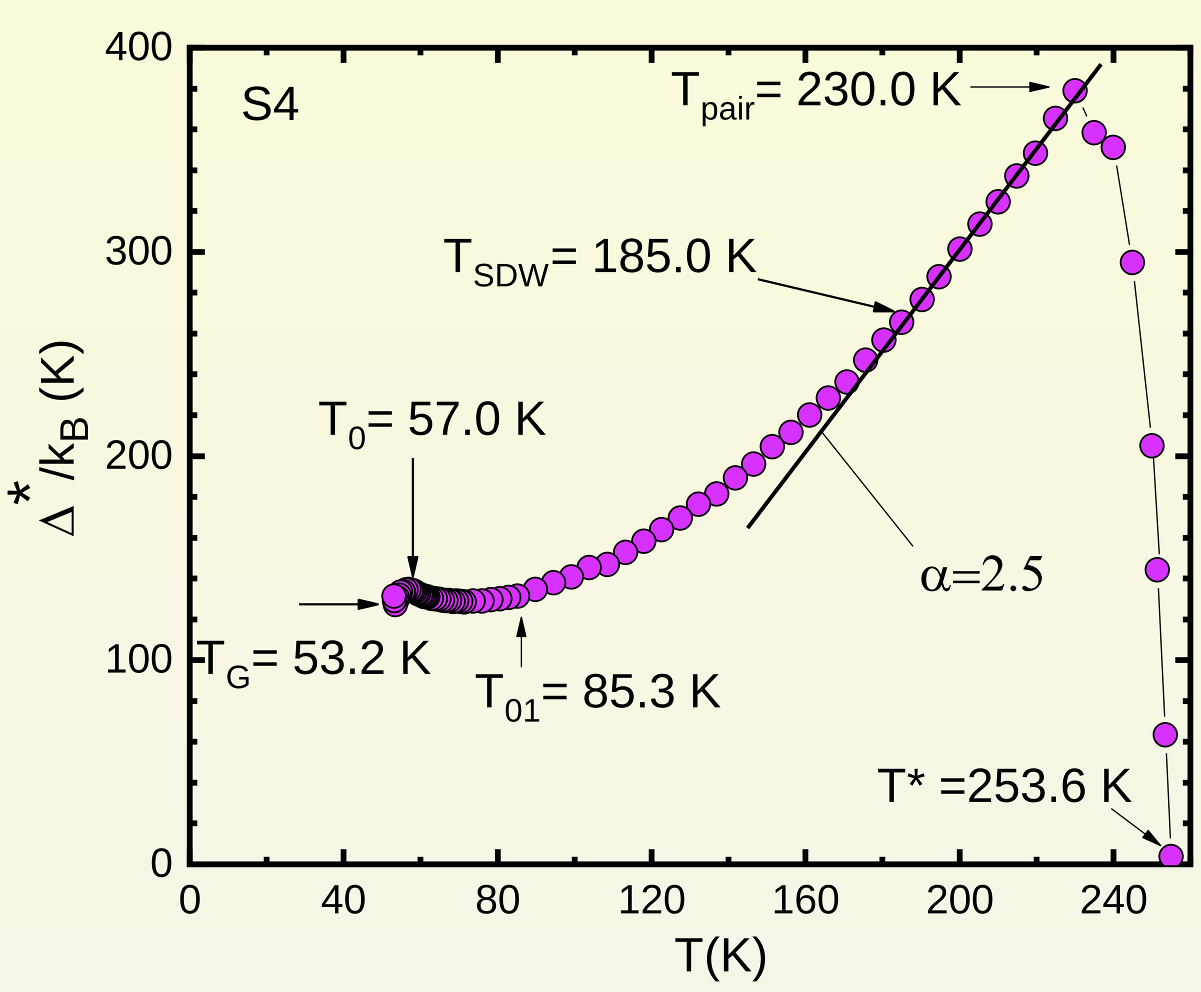
$$\sigma'_{MT} = \frac{e^2}{8d\hbar}\cdot\frac{1}{1-\alpha/\delta}\cdot\ln\left((\delta/\alpha)\cdot\frac{1+\alpha+\sqrt{1+2\alpha}}{1+\delta+\sqrt{1+2\delta}}\right)\cdot\varepsilon^{-1}$$

L. G. Aslamazov and A. L. Larkin, Phys. Lett., 26A, 238 (1968).

Results.

Temperature dependences of the pseudogap Δ*(T) for the as-grown SD single crystal of $Y_{0.66}Pr_{0.34}Ba_2Cu_3O_{7-\delta}$.





$$\Delta^*(T) = T\ln\left[\frac{e^2 A_4\left(1-\frac{T}{T^*}\right)}{\sigma'(T)16\hbar\xi_c(0)\sqrt{2\varepsilon^*_{c0}\sinh\left(\frac{2\varepsilon}{\varepsilon^*_{c0}}\right)}}\right]$$

In our work, for the first time, we carried out the analysis of the influence of hydrostatic pressure up to 0.97 GPa on the temperature dependence of pseudogap Δ*(T) of the SD $Y_{0.66}Pr_{0.34}Ba_2Cu_3O_{7-\delta}$ single crystals It is shown that the pressure effect on Tc and resistivity ρ(T) is different. Under pressure ρ(T) decreases linearly at a rate dlnρ(100K)/dP= -14%GPa^{-1}, while Tc increases at a rate dTc/dP= +2.88 $KGPa^{-1}$, which is associated with the redistribution of charge carriers in the CuO_2 planes. Near Tc, independently on pressure, σ′(T) is well described by the Aslamasov–Larkin and Hikami–Larkin fluctuation theories, demonstrating 3D–2D crossover with increase of temperature [1].

The crossover temperature T_0 determines the coherence length along the c-axis ξc(0)≃(3.36±0.01)Å at P=0, which decreases to (3.05±0.01)Å, at P= 0.97 GPa. At the same time, Δ*(TG) increases with increasing hydrostatic pressure at a rate dlnΔ*(T_G)/dP=0.10 GPa^{-1}, implying an increase of the coupling strength with increasing P, whereas the BCS ratio 2Δ*(T_G)/k_BTc = 5 remains constant.

The dependence Δ*(T) shows a narrow maximum at high temperatures, which is typical for magnetic superconductors [2] and is due to the presence of magnetic inclusions PrBCO in the sample. Note that the slope of the dependence Δ*(T) below T_{pair} increases with increasing pressure and at P = 0.97 GPa coincides with the slope in the Fe-As base pnictide $SmFeAsO_{0.85}$ [2]. By analogy, it is assumed that below T_{SDW} < T_{pair}, the spin density wave regime is realized in the sample.

[1] A. L. Solovjov, K. Rogacki, Low Temp. Phys. 49, 345–363 (2023) https://doi.org/10.1063/10.0017238 (2023).

[2] A.L. Solovjov, L.V. Omelchenko, V. B. Stepanov et al., Phys. Rev. B 94, 224505 (2016). DOI: 10.1103/PhysRevB.94.224505