Superconductivity:

The Meissner Effect and Measurements of T_c

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Properties of Superconductors

- A material with zero resistance
- Exhibits the Meissner Effect: $B_{sc} = 0$

$$B_{\mathrm{sc}} = Be^{-z/\lambda_L}$$

- $B \sim 0$ past London penetration depth λ_L
- Essentially also a perfect paramagnet

Properties of Superconductors (cont.)

- When $B = 0$, SC phase transition at T_c
- When $B \neq 0$, transition occurs when (T, B) satisfies

$$B = B_0 \left[1 - \left(\frac{T}{T_c} \right)^2 \right]$$

- B_0 is the limiting critical field at $T = 0$

BCS Theory of Superconductivity

- Bardeen, Cooper, and Schrieffer (1957)
- At low temperature, electrons couple into Cooper pairs through vibrations (phonons) in the material lattice
- The Cooper pairs condense into a mutual ground state where currents can flow without resistance

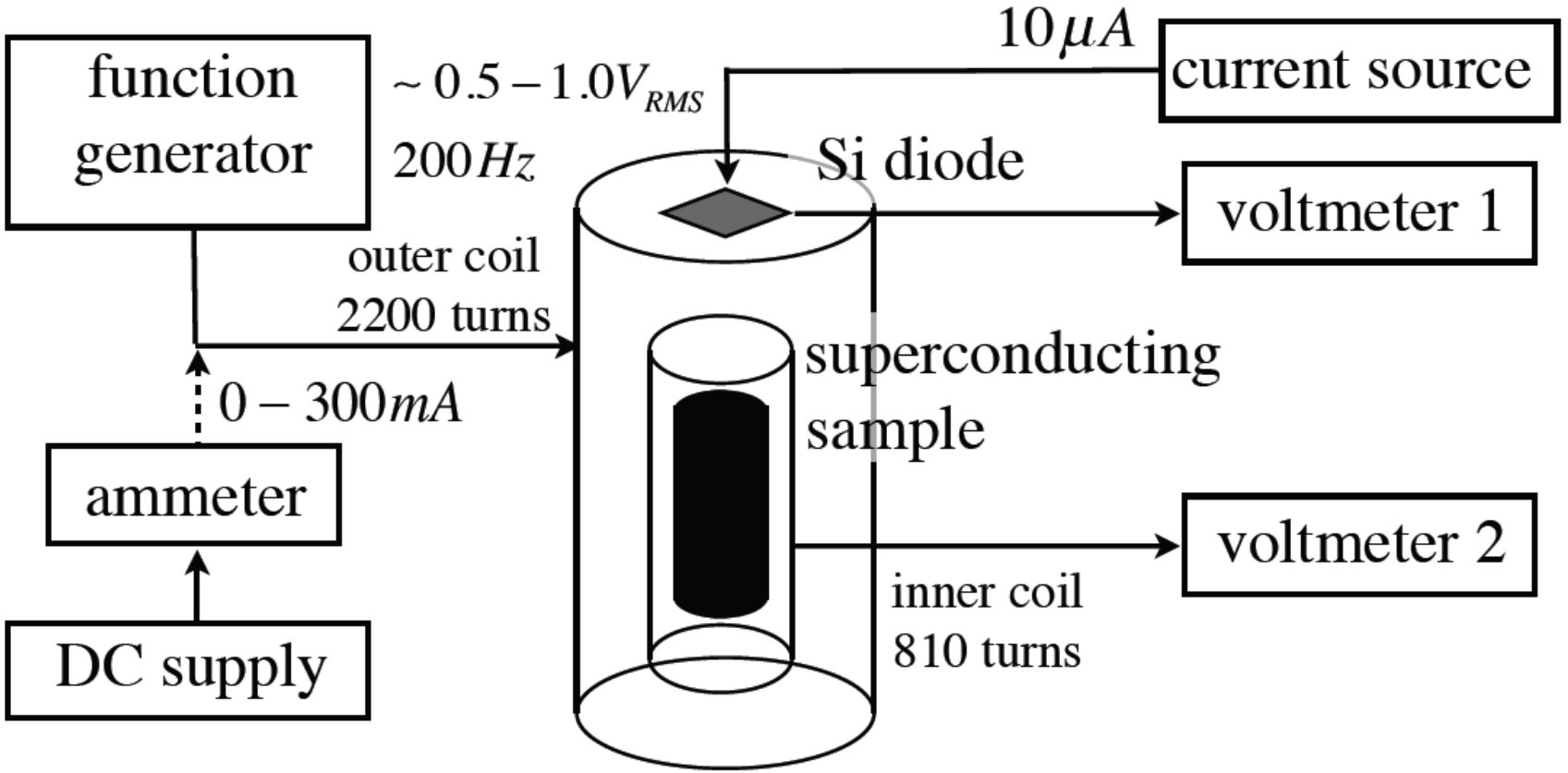
Meissner Effect: T_c Measurements

- Put an SC into an AC driven solenoid and measure the induced EMF at test coil
- When $T > T_c$, get full flux of test coil
- When $T < T_c$, get no flux in SC region
- Can measure T_c by monitoring test coil flux

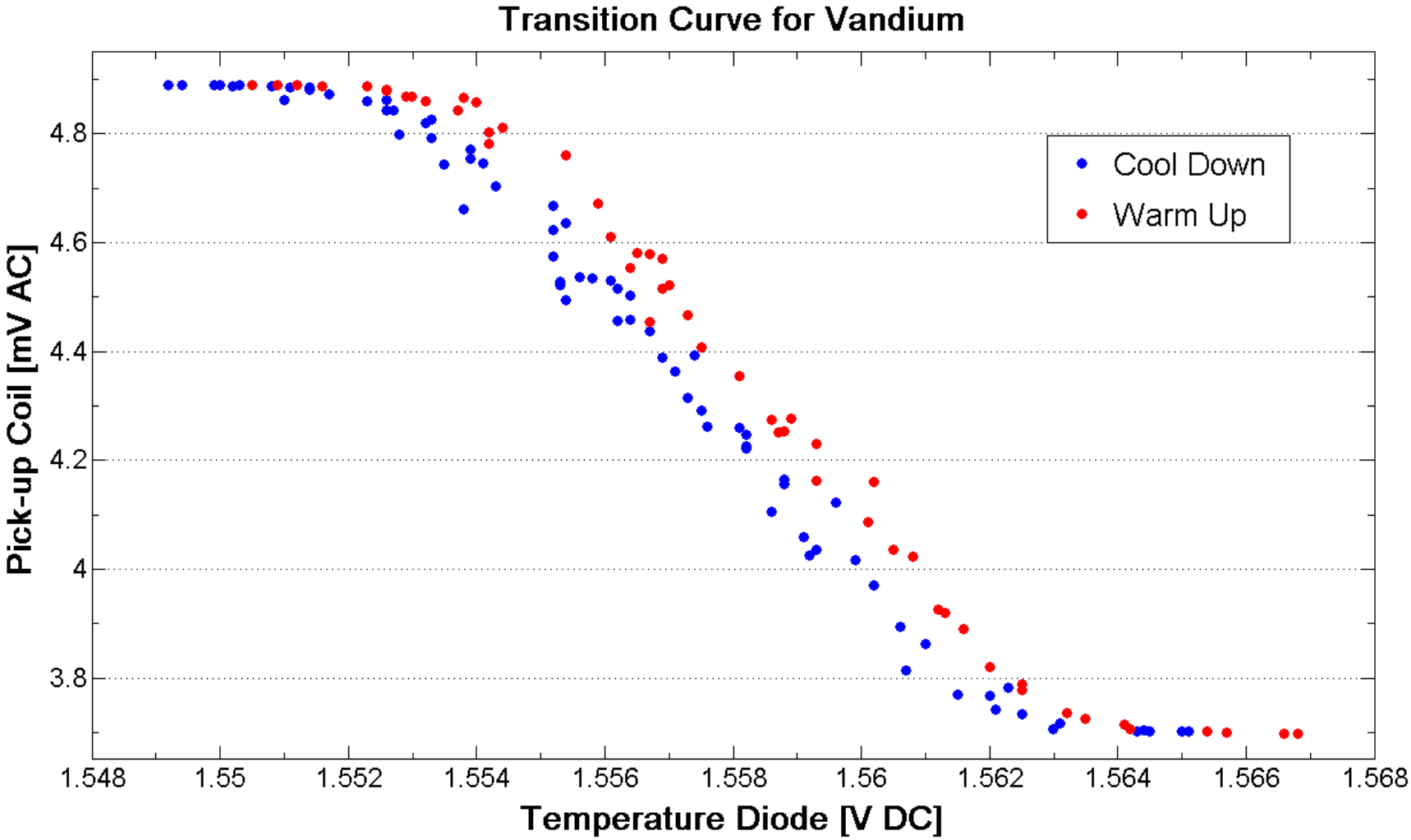
Meissner Effect: Persistent Currents

- Set up $B \neq 0$ at $T > T_c$ for a hollow cylinder of SC material
- After $T < T_c$, surface currents set up to cancel field in material and B in cylinder
- Field inside persists even after B is turned off
- Field inside quenches once $T > T_c$

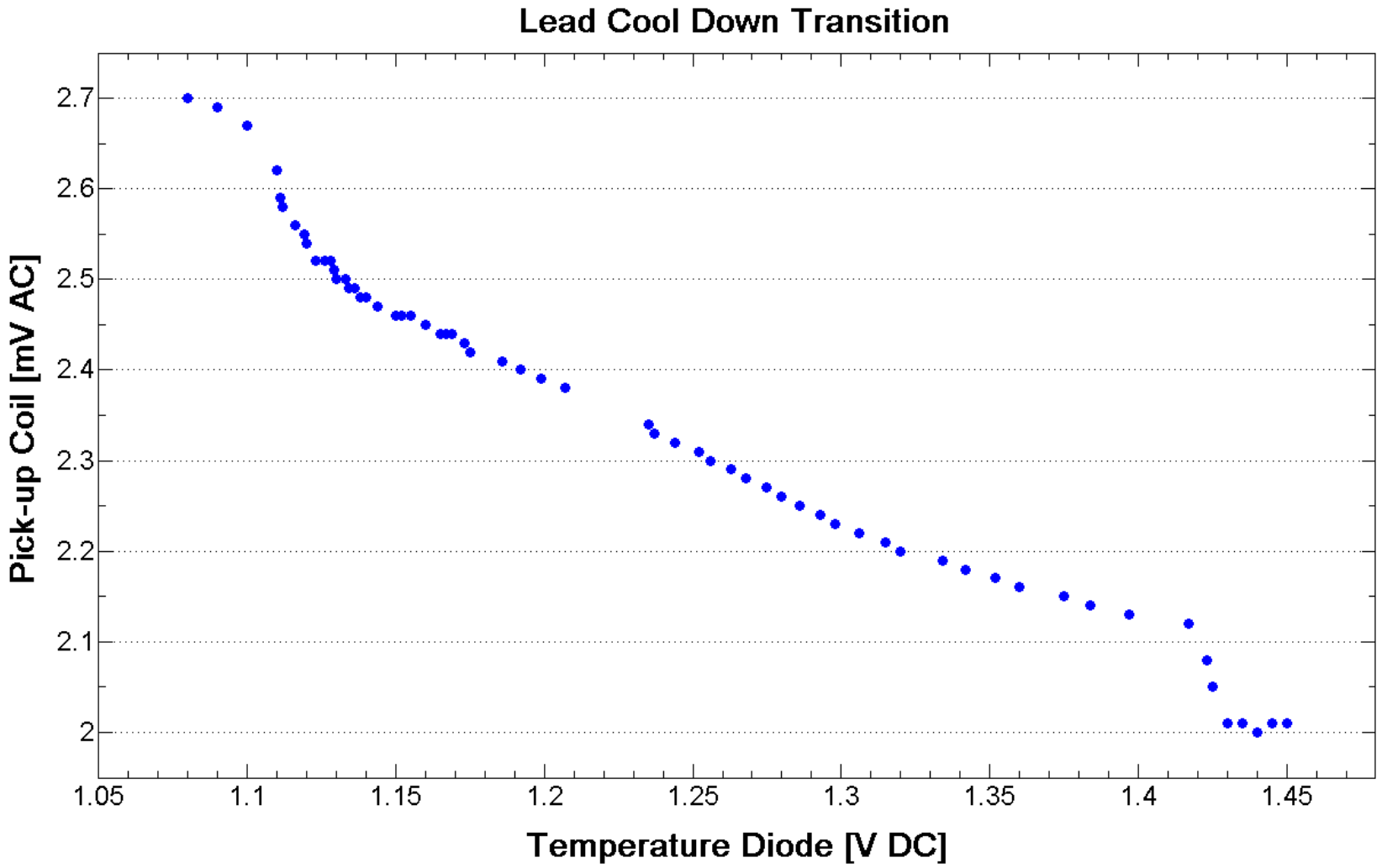
Overview of Probe I



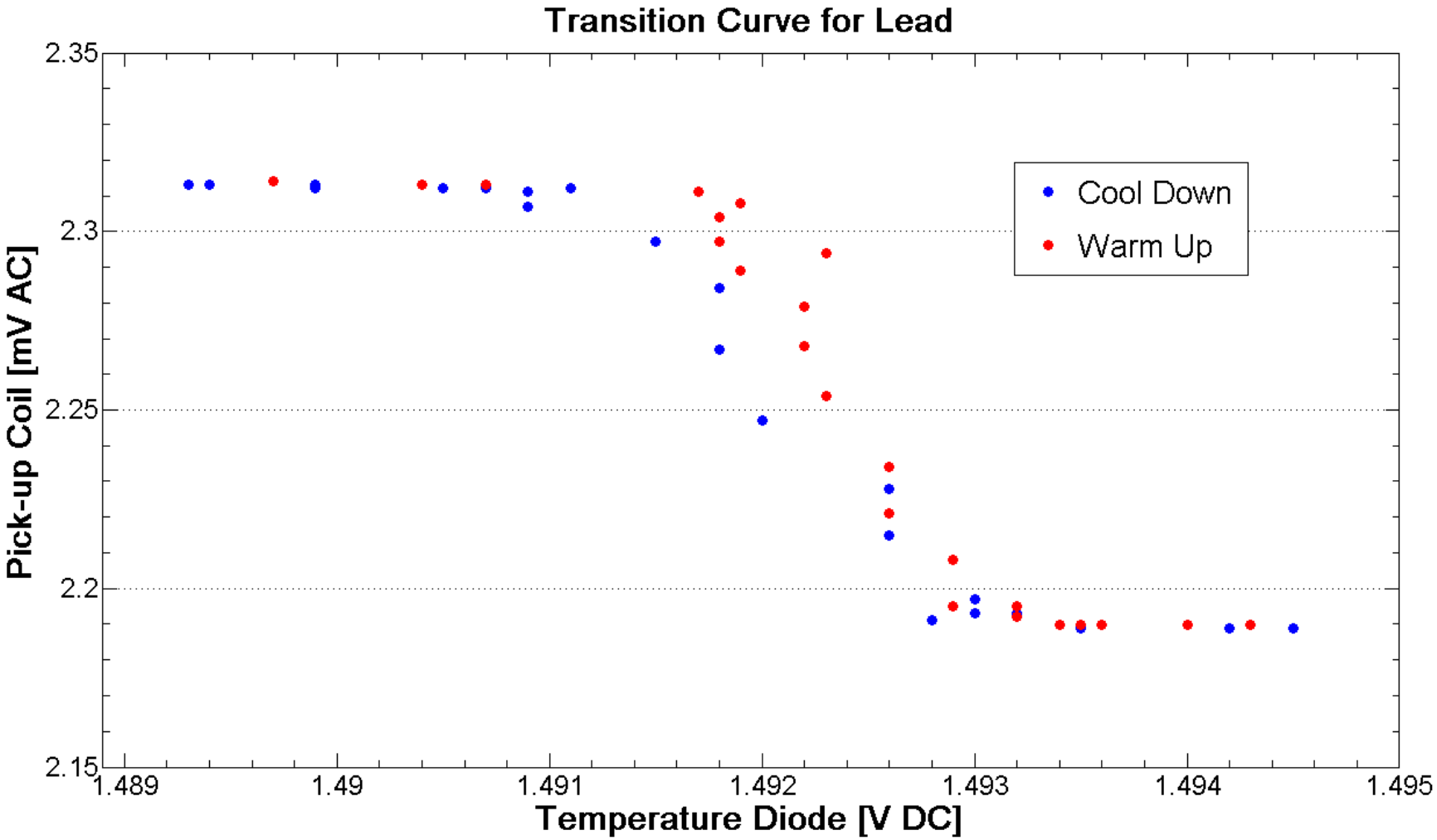
T_c Transition Curves: Vanadium



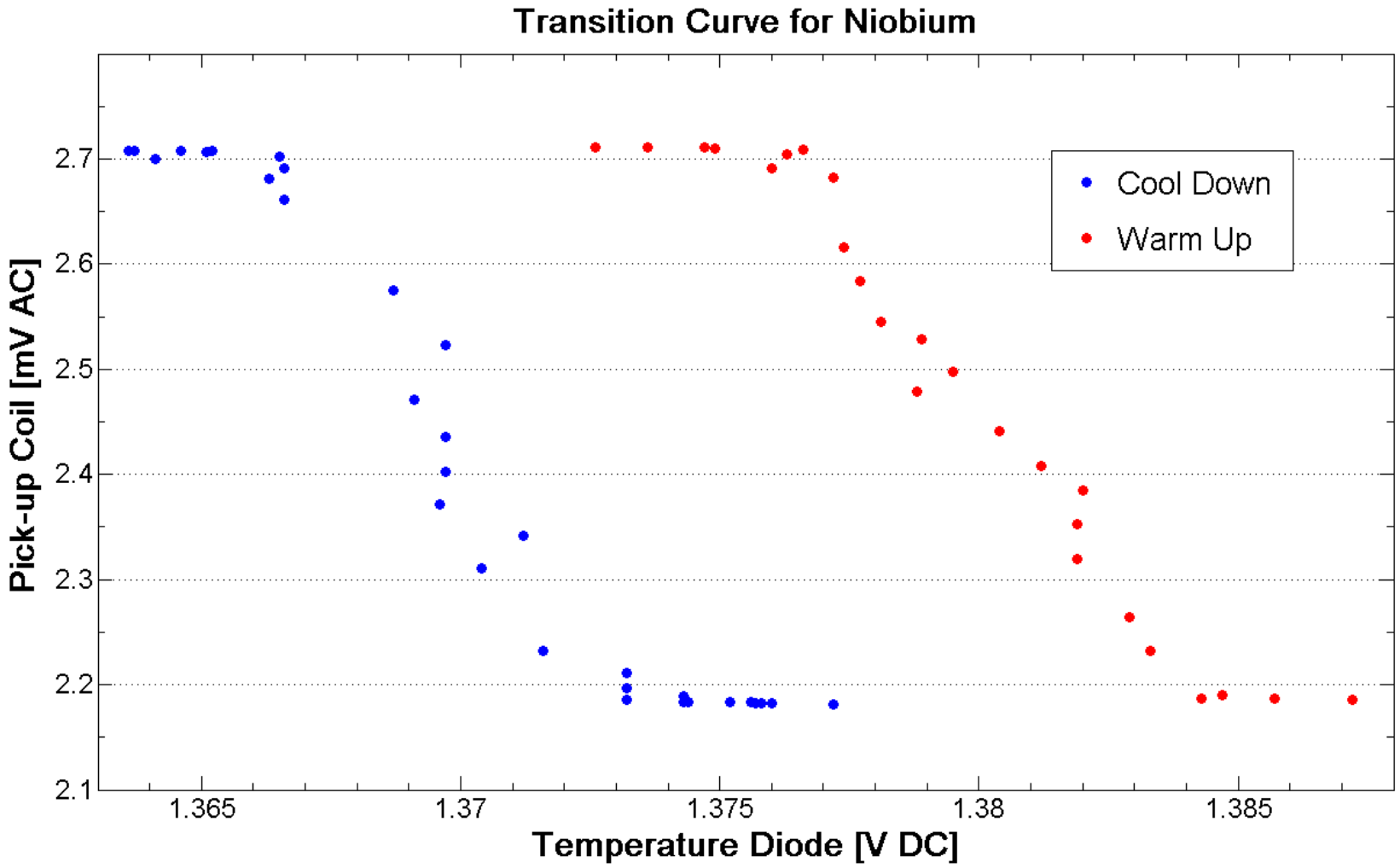
T_c Transition Curves: Lead



T_c Transition Curves: Lead



T_c Transition Curves: Niobium



T_c Fit Procedure

- Find mean of constant regions
- Define midpoint as V_0 with uncertainty δV_0
- Fit $y = ax + b$ to transition region by least-squares regression without uncertainties

$$T_c = \frac{V_0 - b}{a}$$

T_c Fit Procedure (cont.)

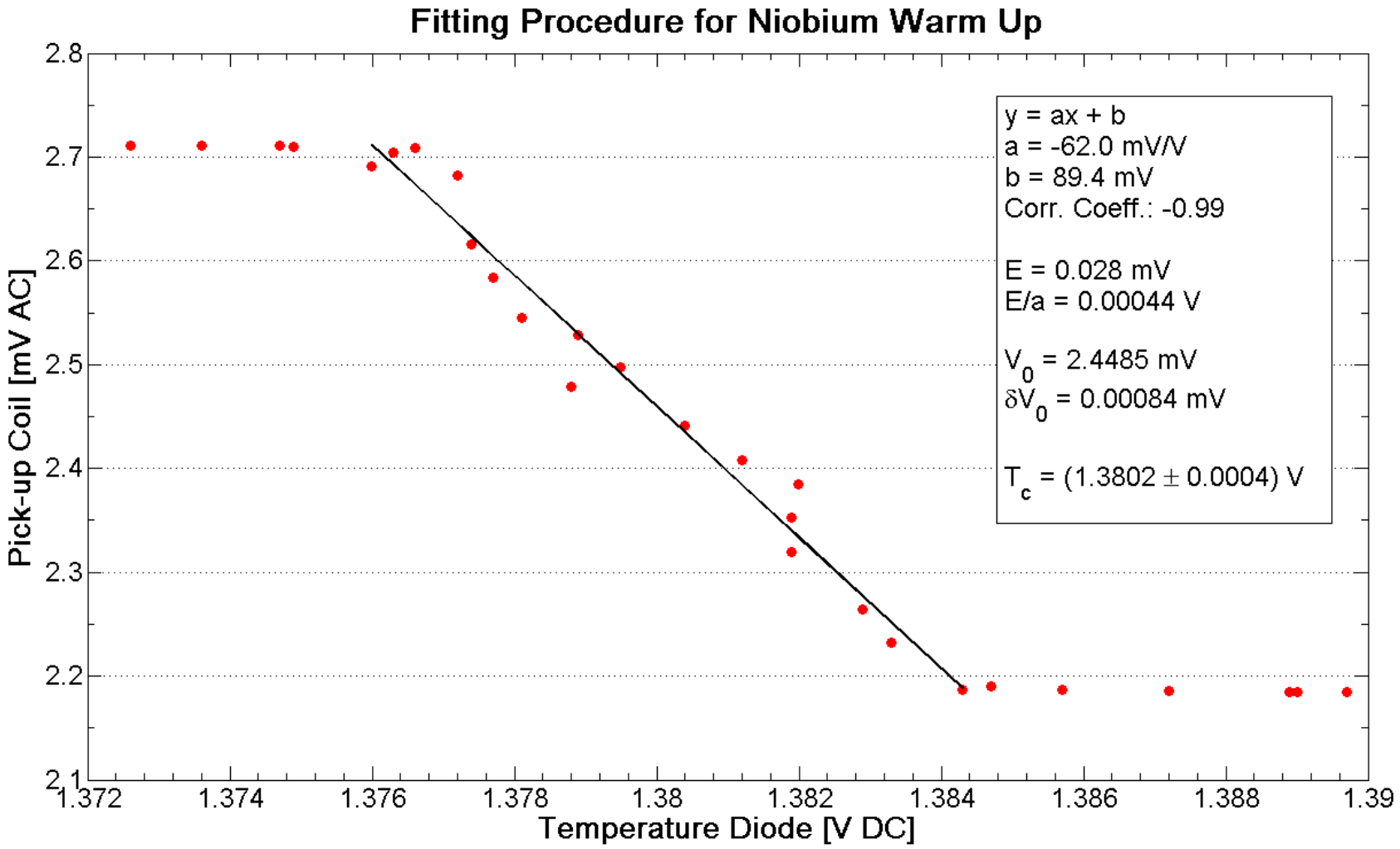
- Define the deviation

$$E = \sqrt{\frac{\sum_i (y - y_i)^2}{N}}$$

- Uncertainty of T_c due to line width is E/a

$$\delta T_c = \sqrt{\delta V_0^2 + (E/a)^2}$$

T_c Fit Procedure: Example



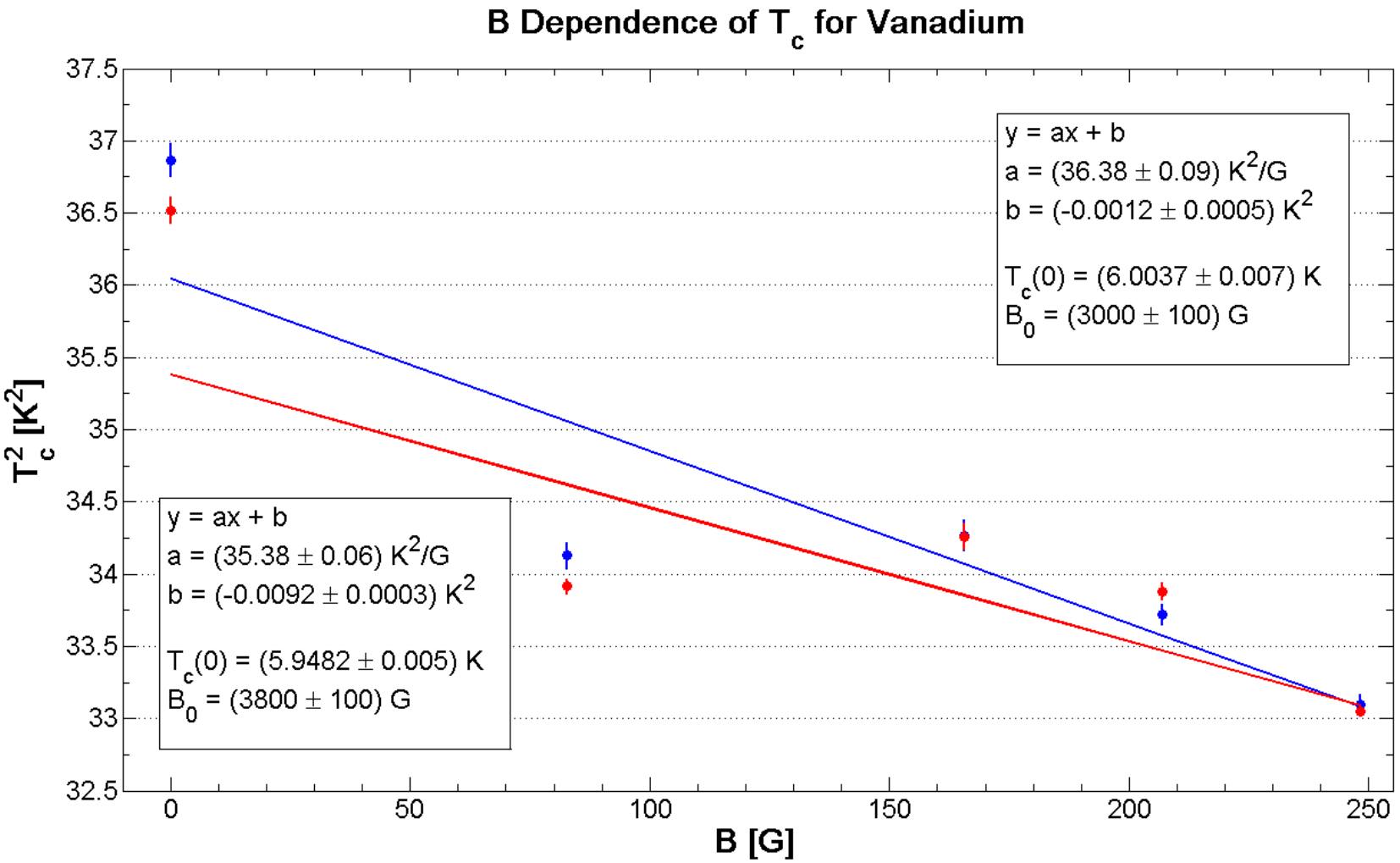
Summary of T_c Transitions

- Summary of T_c fitting procedure

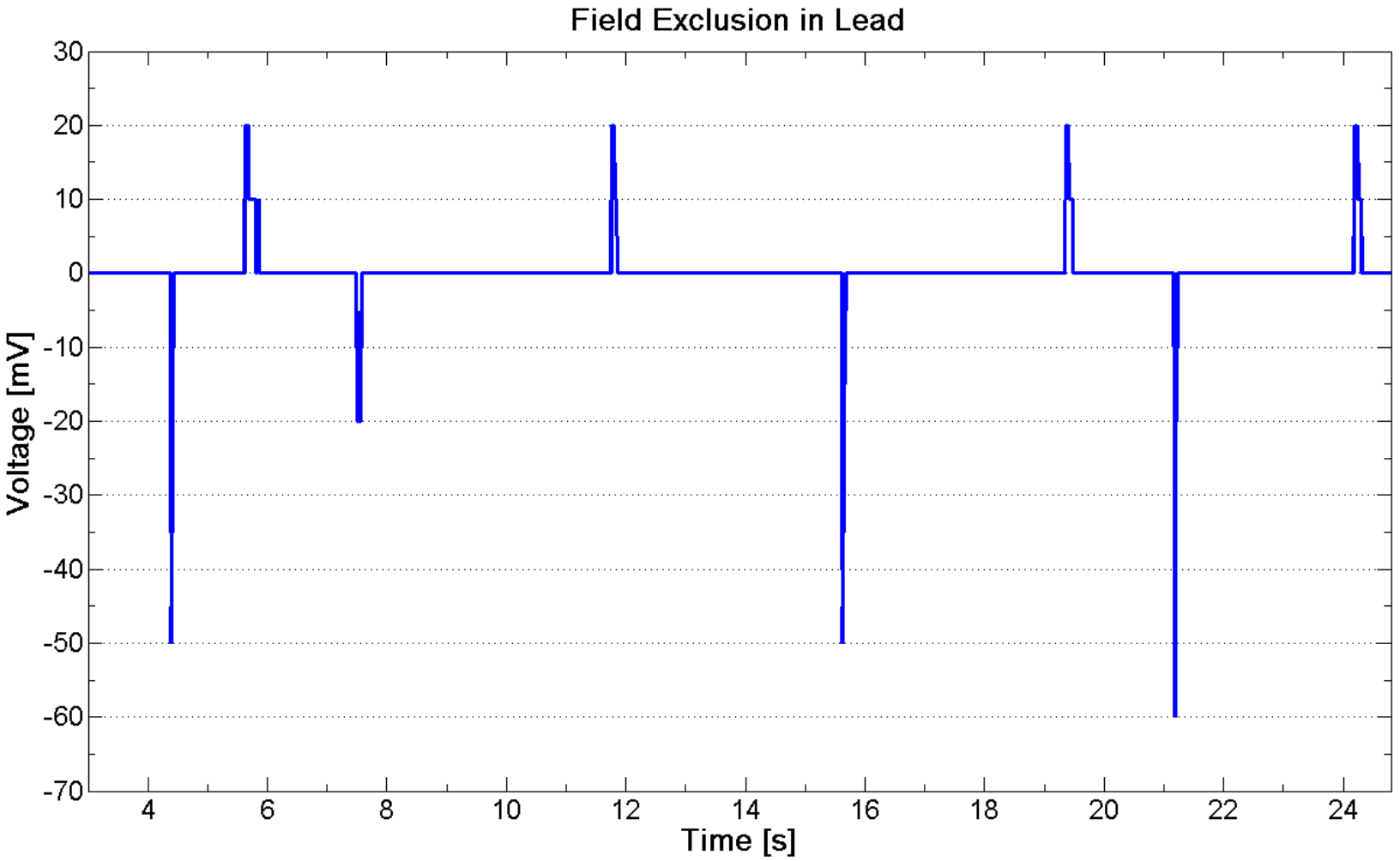
T_c (K)	Cool Down (K)	Warm Up (K)	Error (K)
5.38	6.072 ± 0.009	6.043 ± 0.008	0.66
7.19	7.787 ± 0.004	7.779 ± 0.004	0.59
9.46	11.94 ± 0.03	11.50 ± 0.02	2.04

- There is some hysteresis, esp. for Type II
- Error due to pumping and calibration curve
  - No error at 77 K
  - ~0.5 K error at 4.2 K

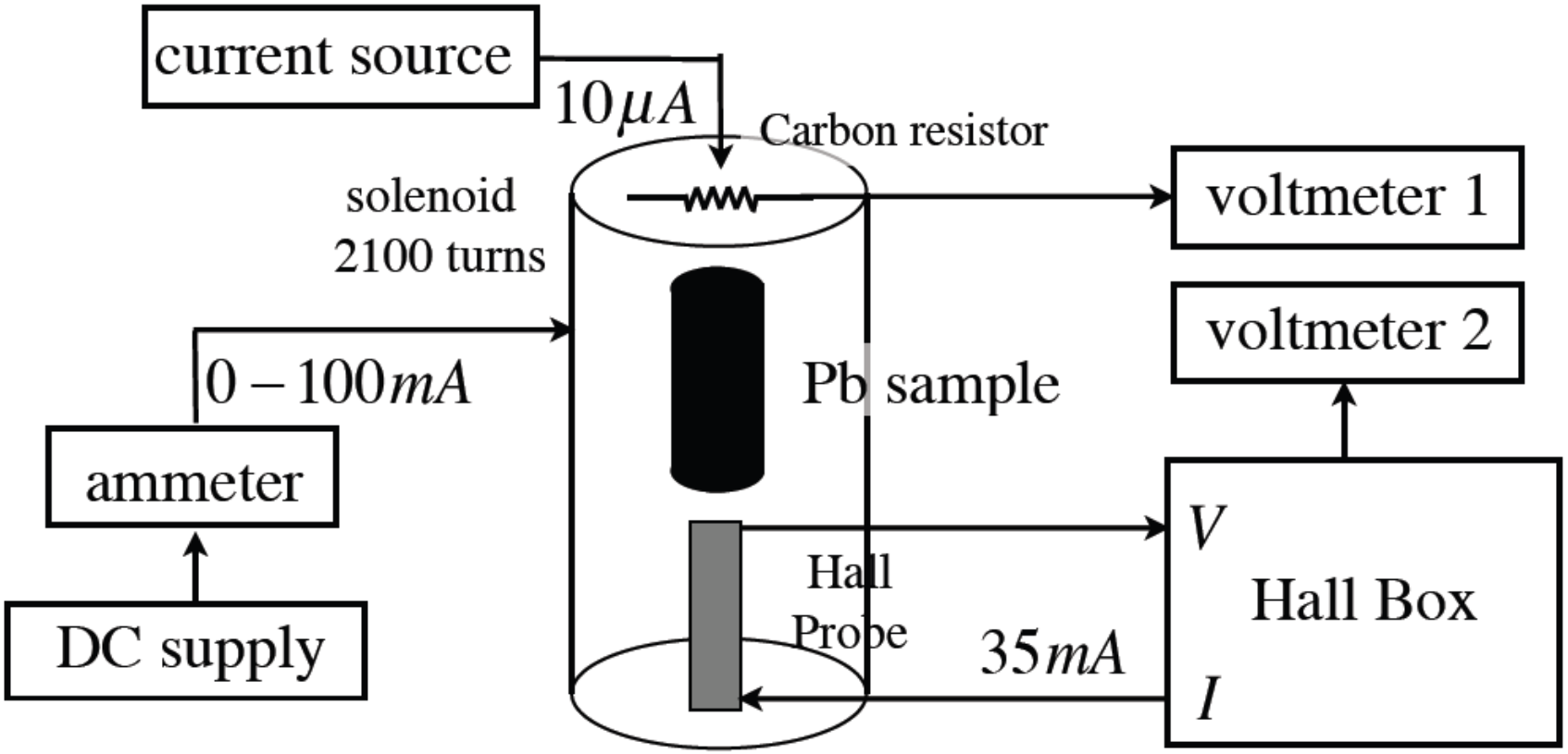
T_c Dependence on B for Vanadium



Field Exclusion in Lead



Overview of Probe 2



Probe 2: Videos

Conclusions

- Observed Meissner effect in superconductors
  - Magnetic flux exclusion (Probe 1)
  - Persistent current (Probe 2)
- Used Meissner effect to measure T_c of various superconducting samples
- Observed B-dependent phase transition curve

Question and Answer