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Insights on the anti-Q-slope in nitrogen doped cavities

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Outline

- Introduction
- Previous works
- Study goals & procedure
- Results
  - $\longrightarrow$ Fixed London penetration depth λ_L
  - $\longrightarrow$ Fixed reduced gap $\Delta/_{\kappa T_c}$
  - $\longrightarrow$ R_{BCS} vs mean free path
- Conclusions

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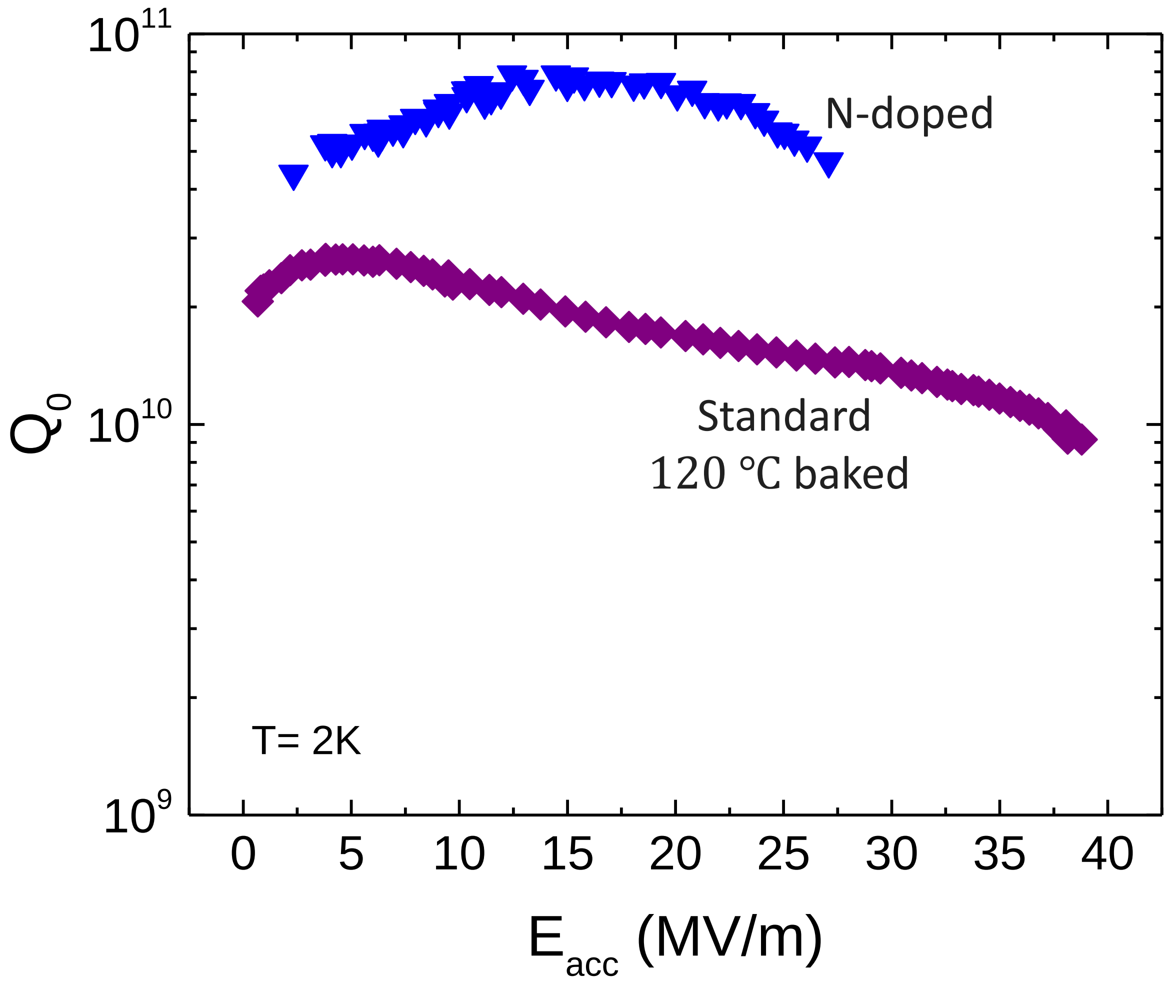
Ultra-high Q-factor

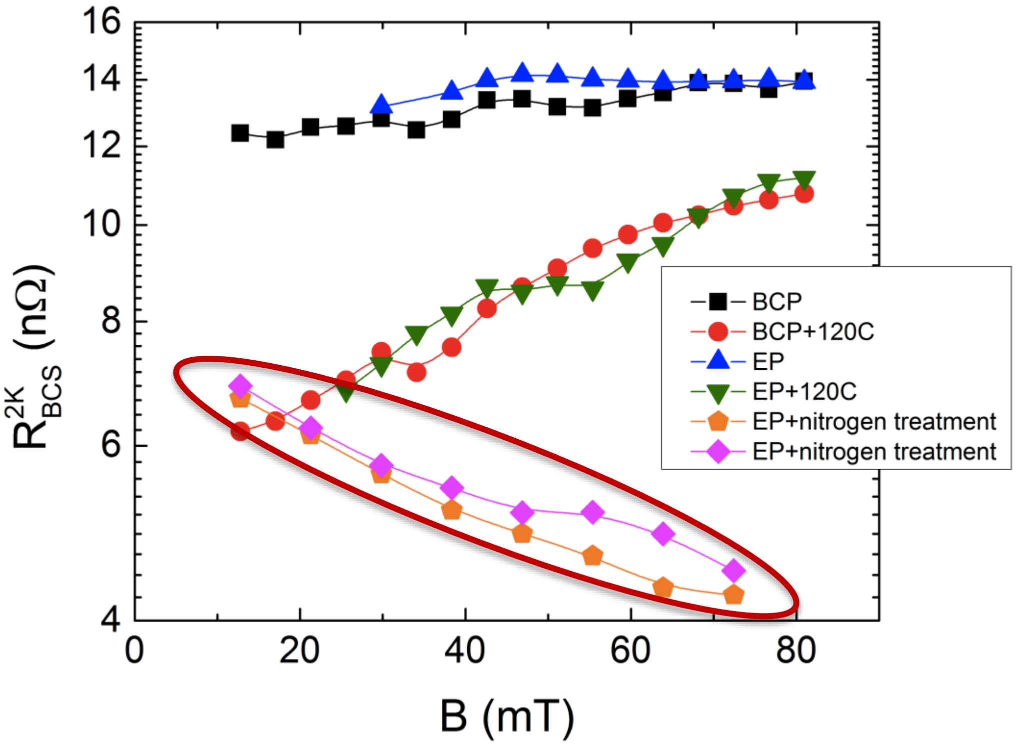


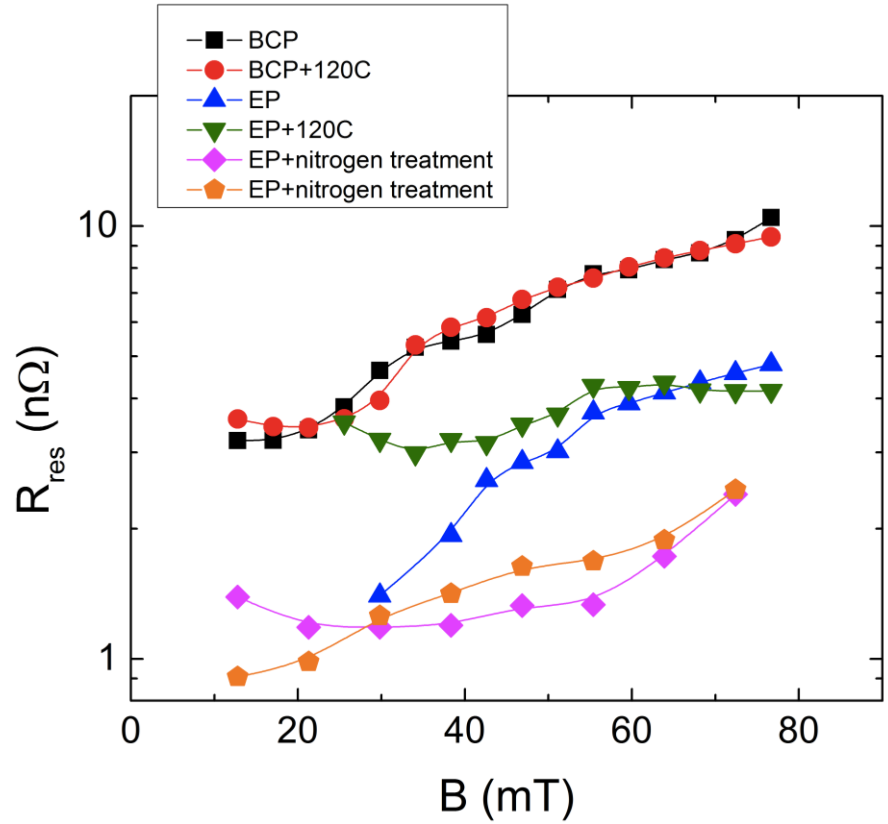
A. Grassellino et al, Supercond. Sci. Technol. **26** 102001 (2013) (Rapid Communication)

Anti-Q-slope evidence in N-doped cavities

Anti-Q-slope =

R_{BCS} decreasing with field!





A. Romanenko and A. Grassellino, Appl. Phys. Lett. **102**, 252603 (2013)

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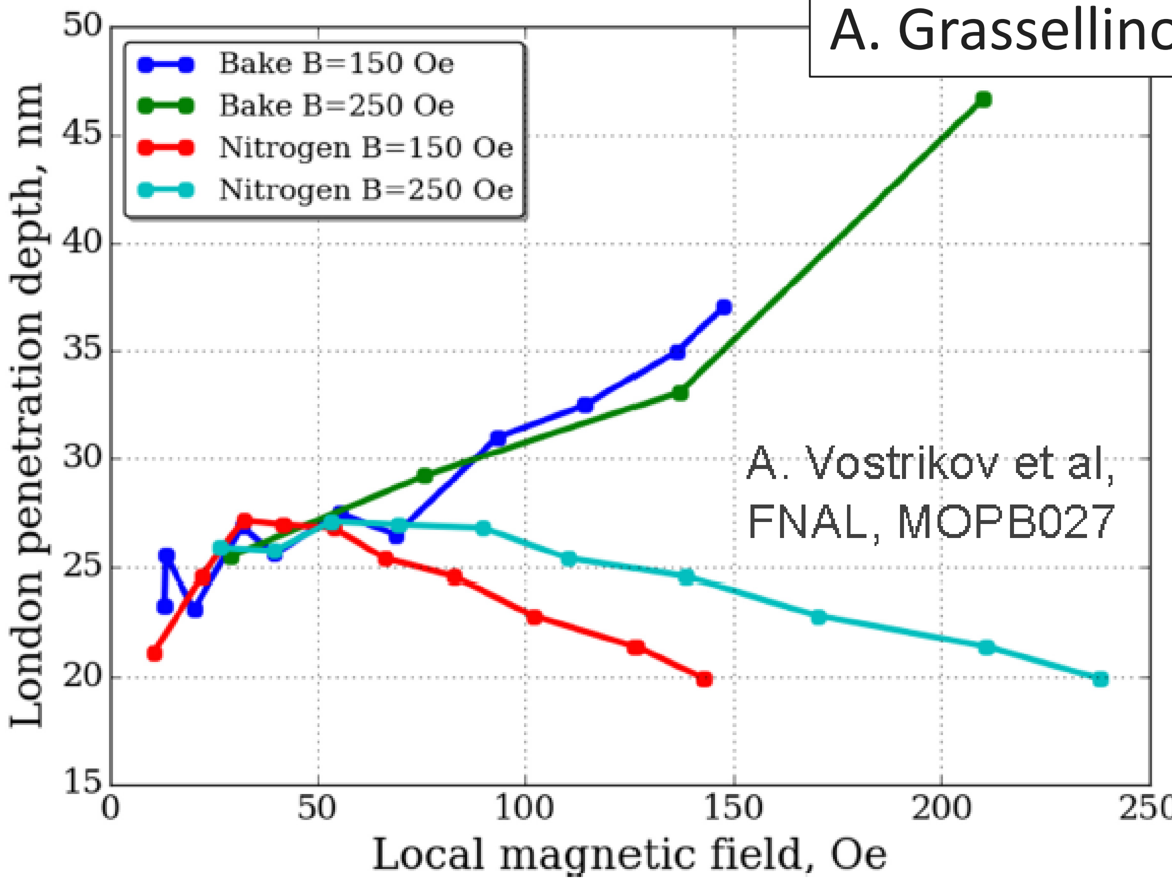
Field dependence of the penetration depth – a possible explanation for the field dependence of BCS R_S?

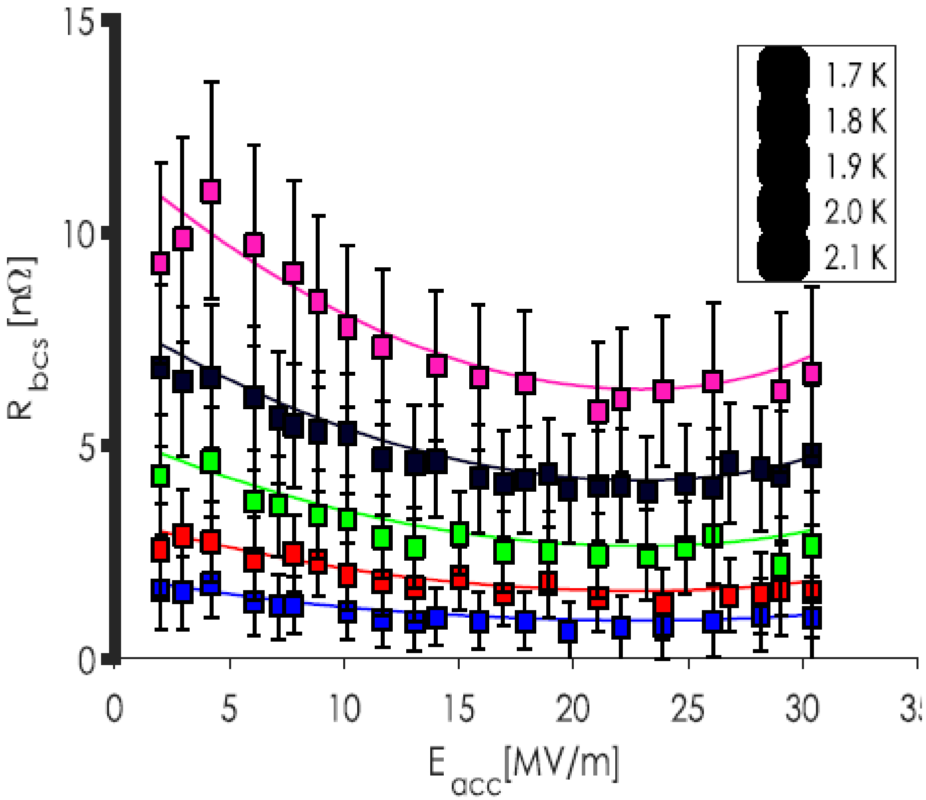
A. Grassellino, SRF 2015

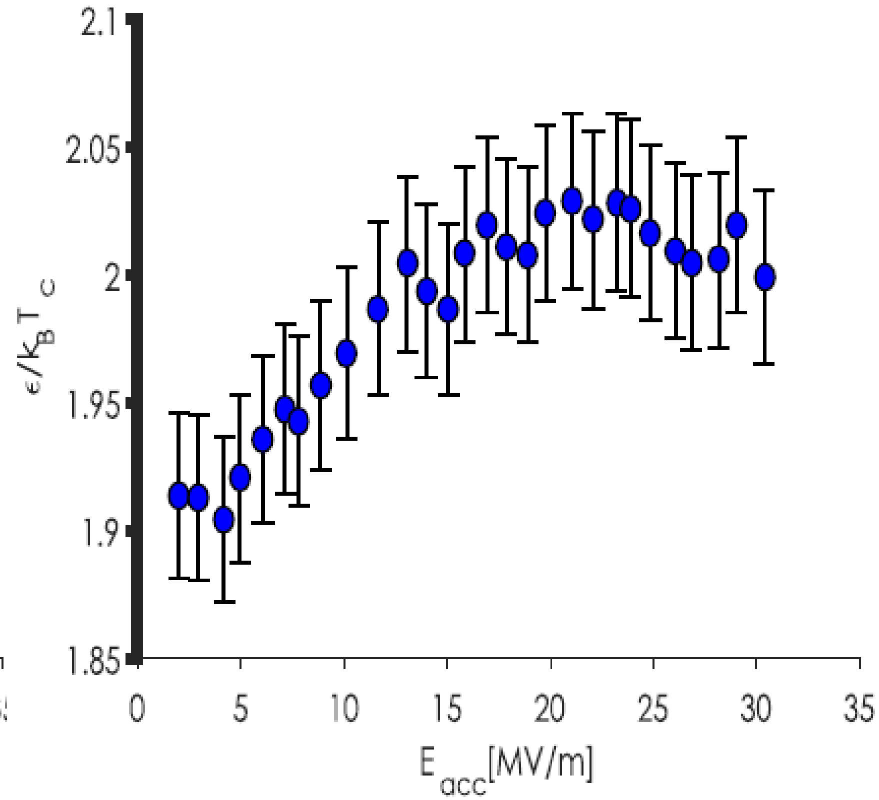


LEM muSR measurements on 120C bake and doped cavity cutouts revel that the penetration depth in the two cases have opposite field dependences, decreasing with field for N doping: possible origin of Q antislope?

N-Doping Effect on Q_0: $R_{BCS}(E_{acc})$ Studies

M. Liepe, SRF 2015

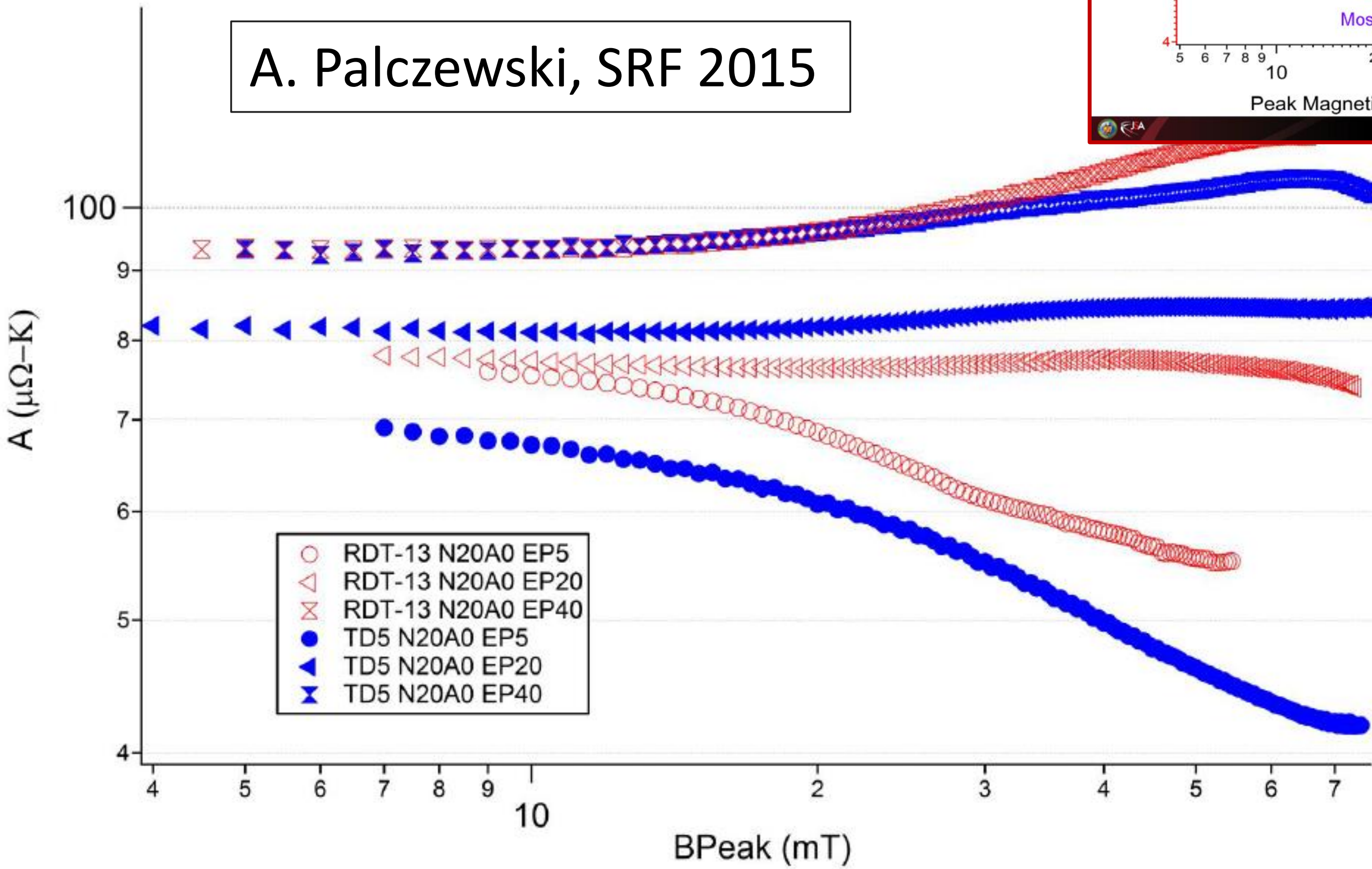


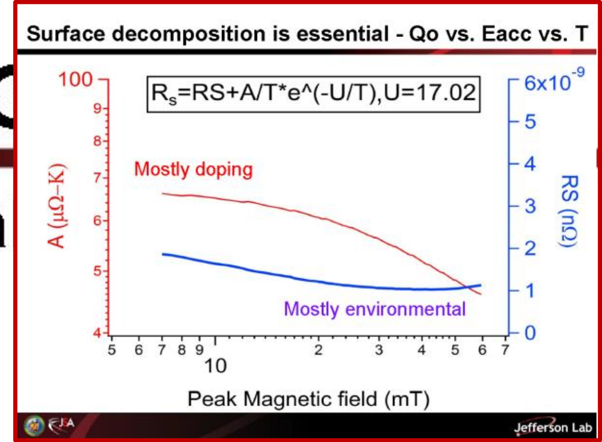


<u>Conclusion</u>: Observed field dependency of temperature depended part of surface resistance well described by assuming field dependent effective spectral gap.

Systematic doping vs. EP (FC

Fitting results remove environmenta





Palczewski et al. – this conference MOPB039 today

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Study goals

Questions:

i. What are the SC parameters that can explain the anti-Q-slope?
ii. Is that possible to identify them by fitting RF test data?
iii. How the SC parameters of N-doped cavities compare with non-doped ones?

Main result:

Using SRIMP we demonstrate that the anti-Q-slope can be described either by:

$\longrightarrow$ the variation of penetration depth with the field, or

$\longrightarrow$ the variation of energy gap with the field

But, we cannot discriminate which is the driving mechanism!

Preamble

- The use of SRIMP in the determination of field dependent parameters is limited: Mattis-Bardeen theory is a zero field description of surface resistance
- The SC parameters value obtained with such fits are to be considered qualitative, because of the model used (Mattis-Bardeen), and because of the large number of arbitrary parameters
- Still, quantitative information can be obtained for R_0 and R_{BCS}

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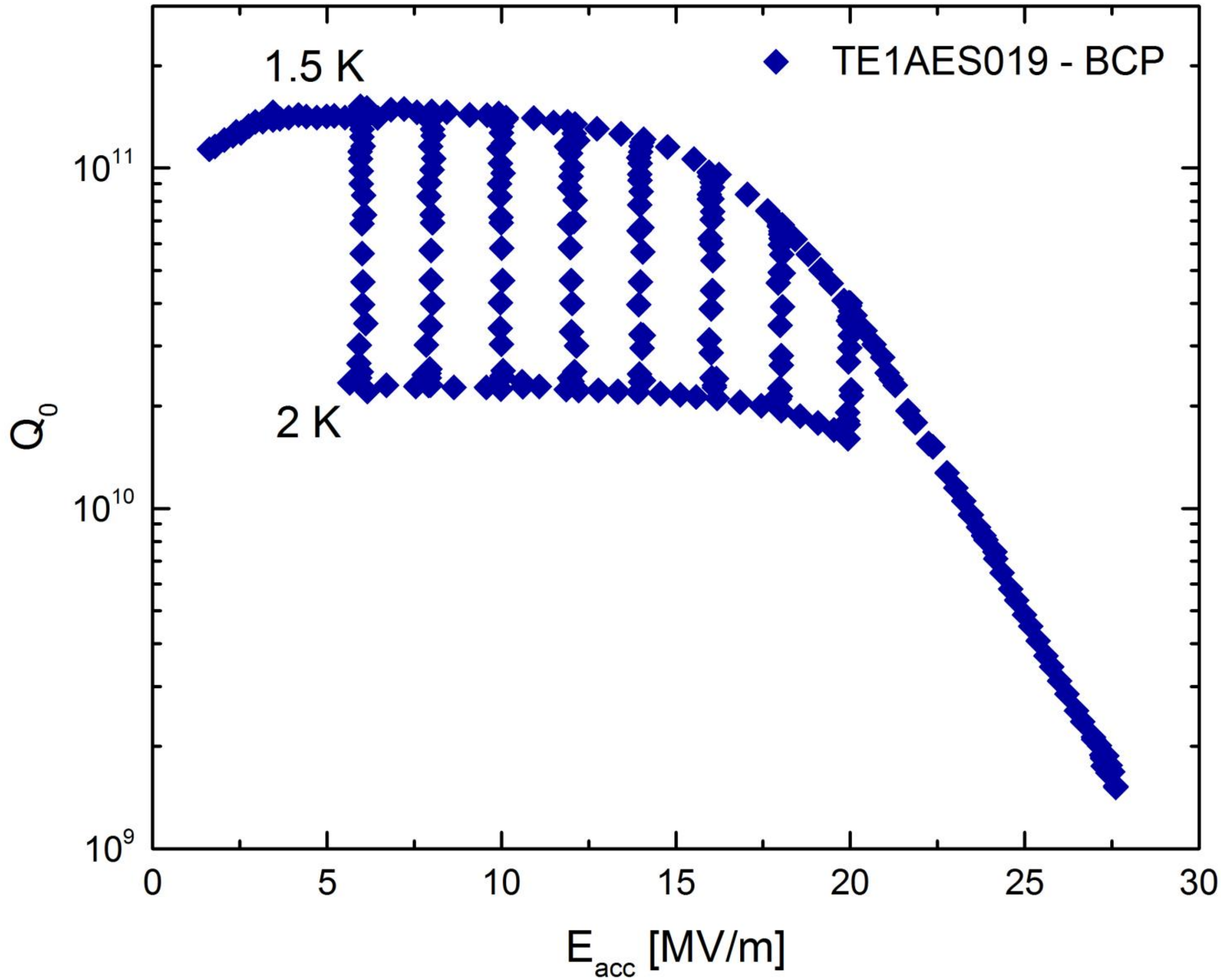
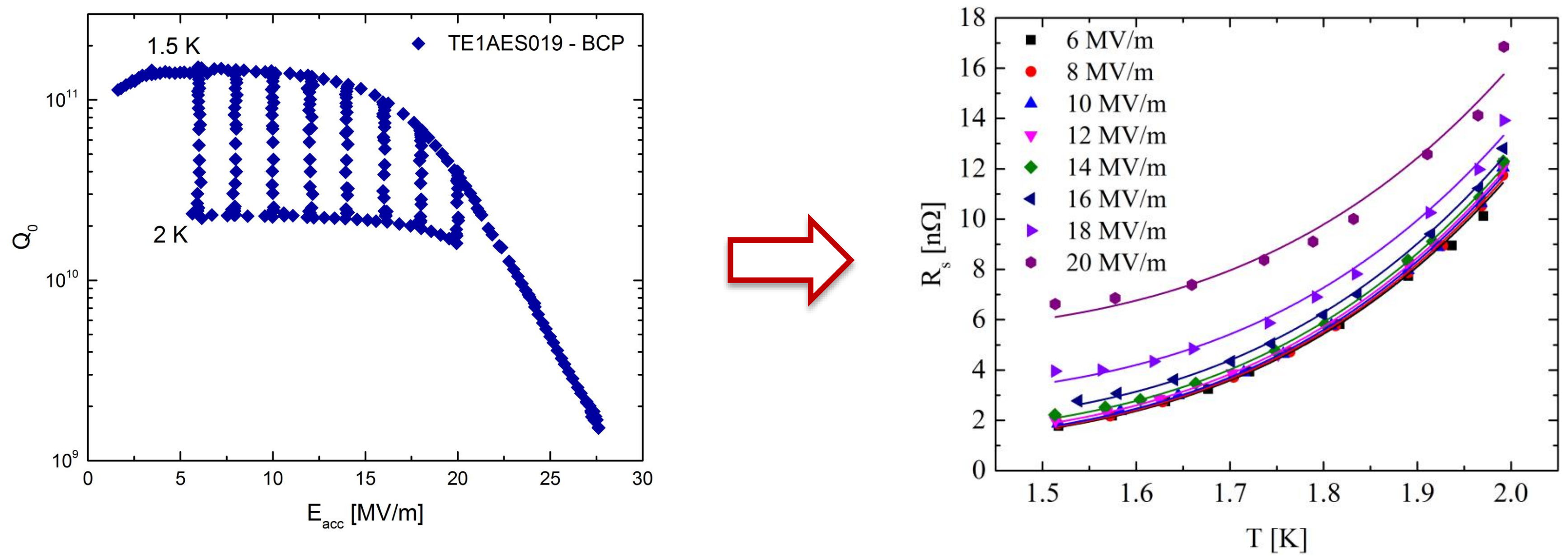
Data acquisition example



Fitting procedure

- We fit Q_0 vs T data in order to extract SC parameters, such as λ_L and Δ, as a function of field
- A C++ translation of SRIMP[1] was used with the OriginPro 2015 Global fit utility[2]



[1] J. Halbritter, FORTRAN program for the computation of the surface impedance of superconductors, KFK-Extern **3/70-6** (1970)
[2] as in: A. Romanenko and A. Grassellino, Appl. Phys. Lett. **102**, 252603 (2013)

Parameters

Cavity	Treatment	T_c [K]	l [Å]	$\frac{\xi_0 \pi}{2}$ [Å]	$\frac{\Delta}{\kappa T_c}$	λ_L [Å] when fixed
te1aes005	1 h 1000 C with N_2 + 80 µm EP	9.25	1500	620	1.944#	250*
te1aes009	Doped @ J-Lab	9.25	400+	620	1.920#	250*
te1aes012	120 C baked	9.25	20*	620	1.804#	250*
te1aes014	EP	9.25	>10000+§	620	1.793#	250*
te1aes019	BCP	9.25	>10000+§	620	1.839#	250*
tb9ri022	120 C baked	9.25	20*	620	1.870#	250*

* LE-µSR

\+ SRIMP

§ Drude resistivity (@ 9.5 K)

\# Average from fit with fixed λ_L

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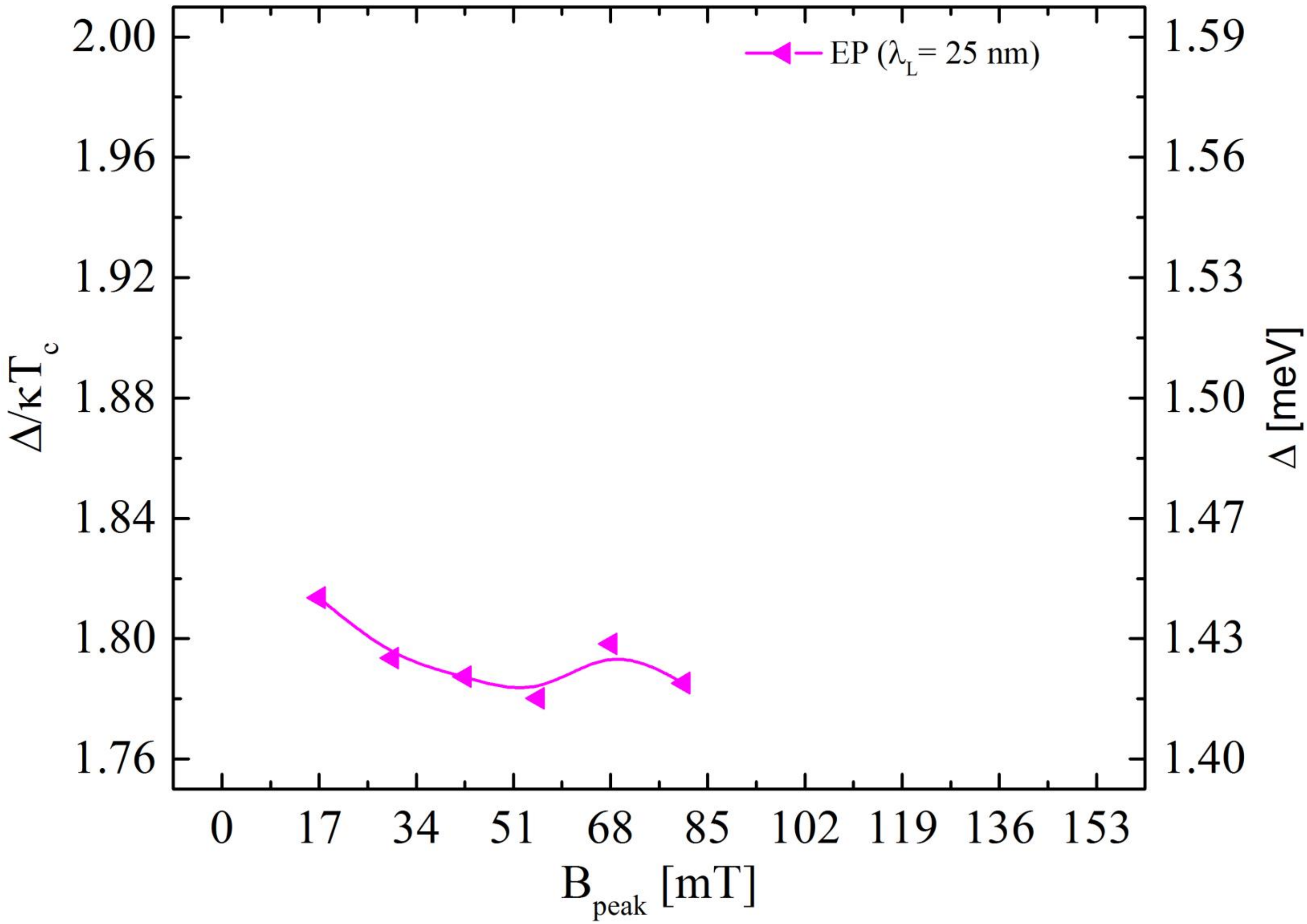
Fit: fixed λ_L, Δ free to vary

- *Fixed parameters*:
  $\rightarrow$ λ_L obtained from LE-μSR measurements
  $\rightarrow$ l obtained from SRIMP code / Drude model / LE-μSR
  $\rightarrow$ $\pi\xi_0/2 = 620$ Å

- *Free parameters*:
  $\rightarrow$ $\Delta/\kappa T_c$
  $\rightarrow$ R_0

$\Delta/(\kappa T_c)$ as a function of field (fixed λ_L)



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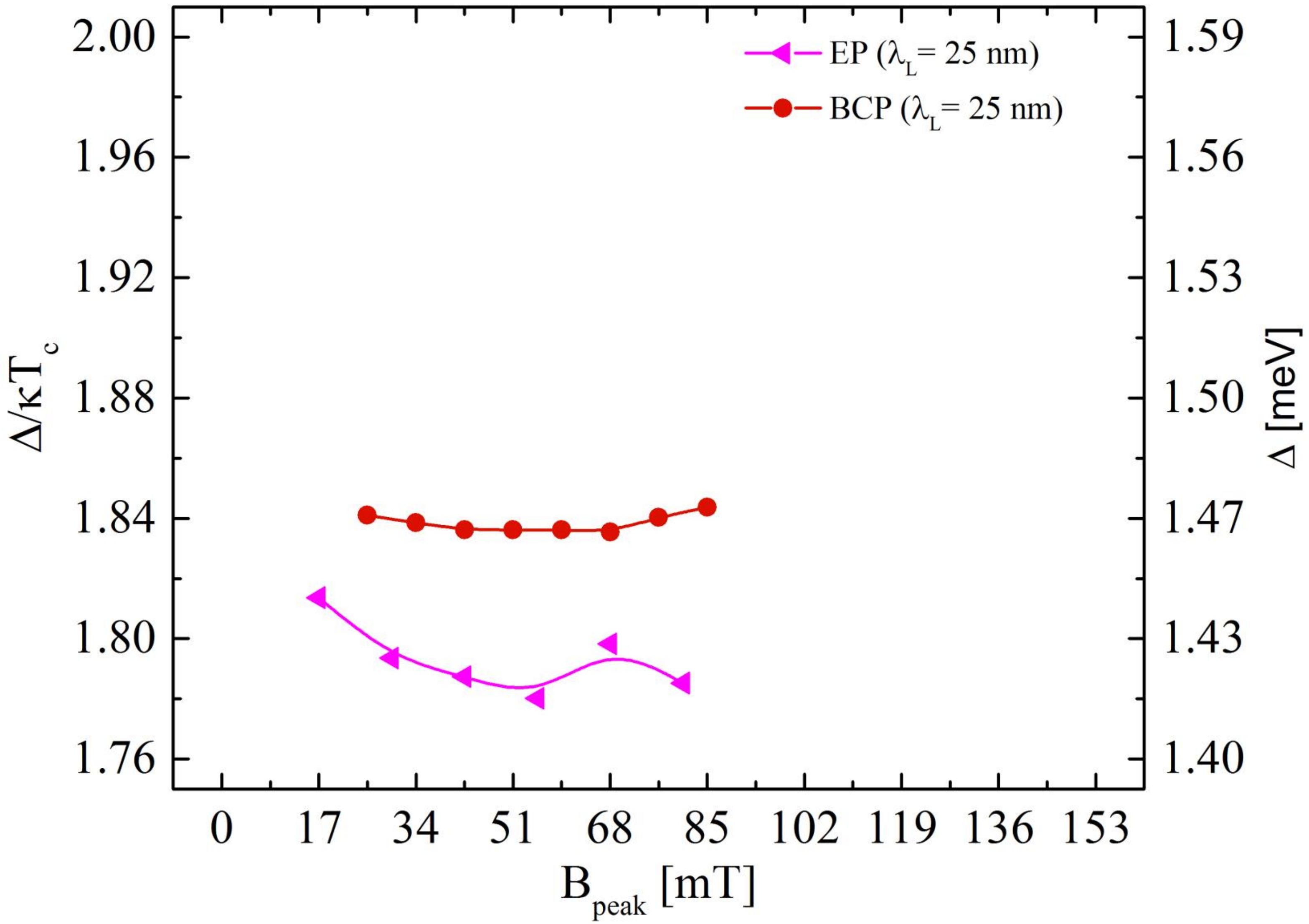

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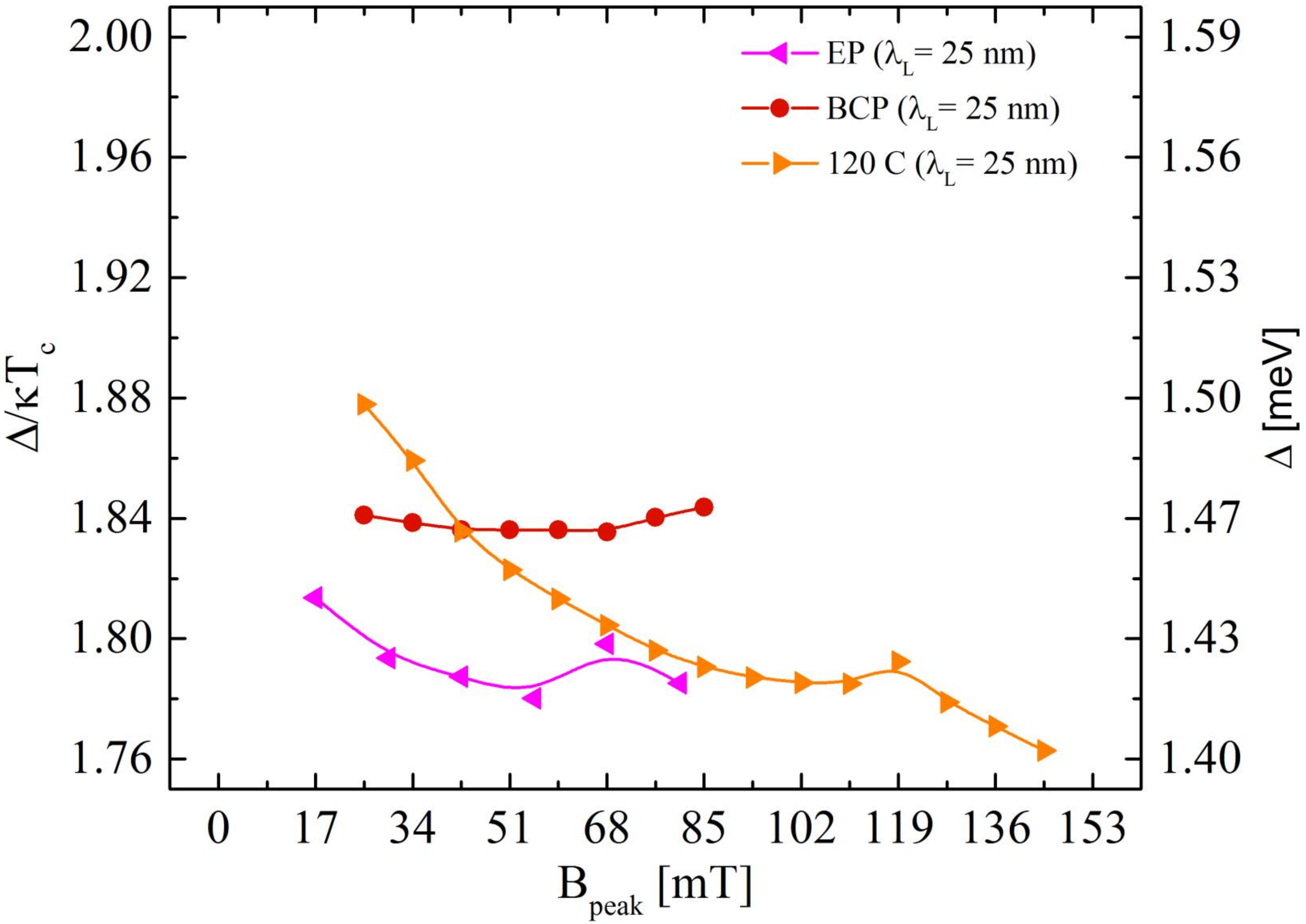

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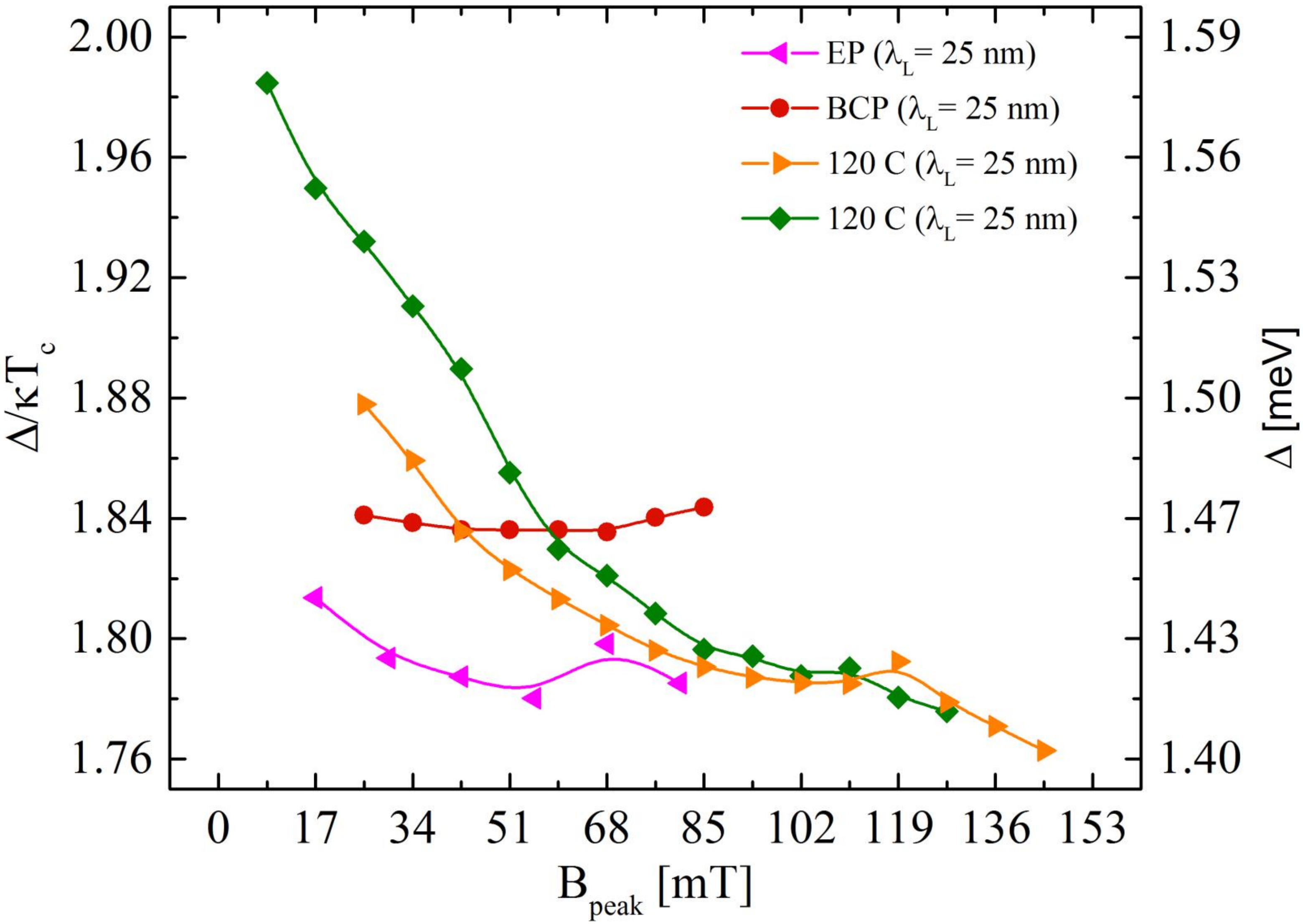

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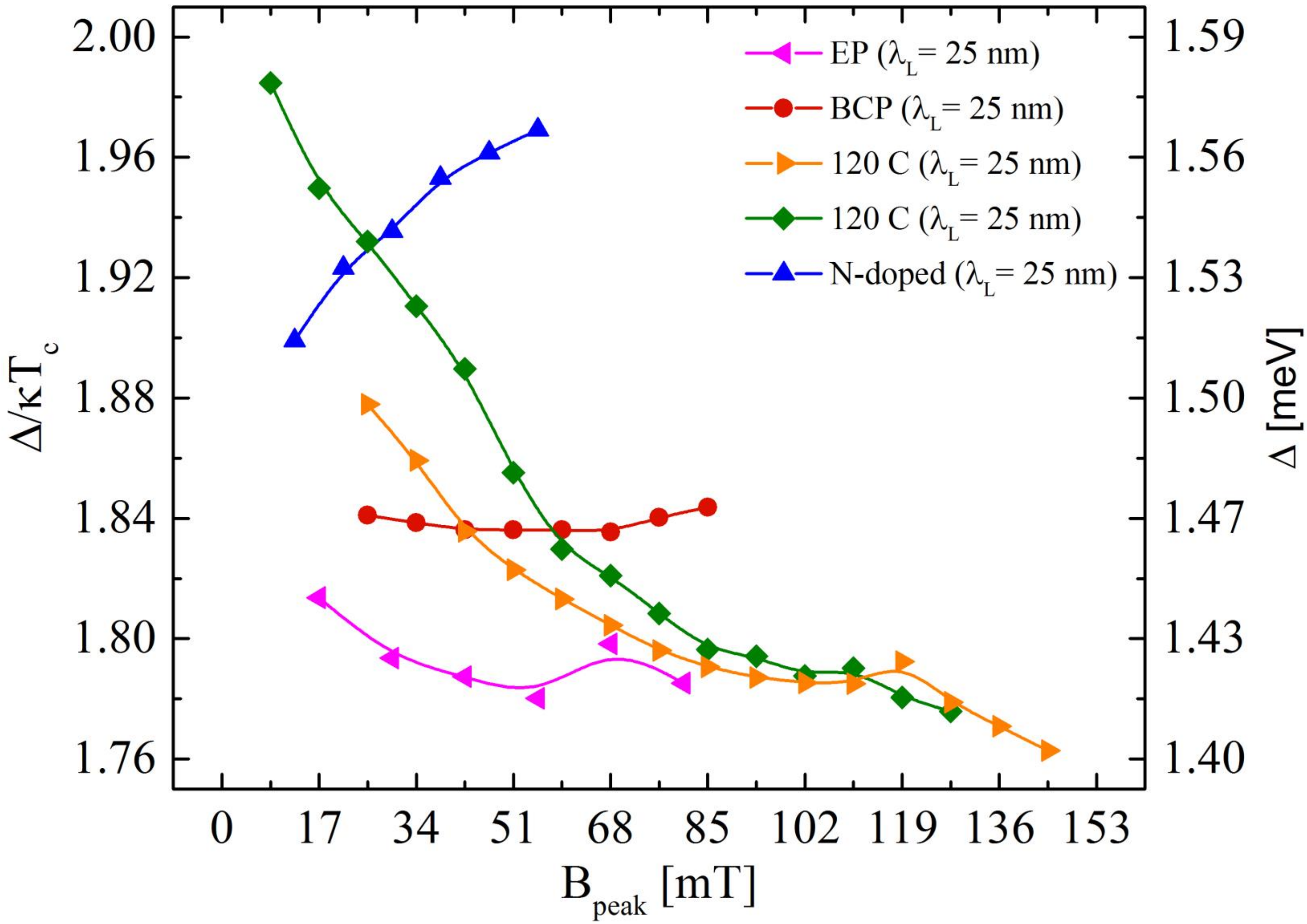

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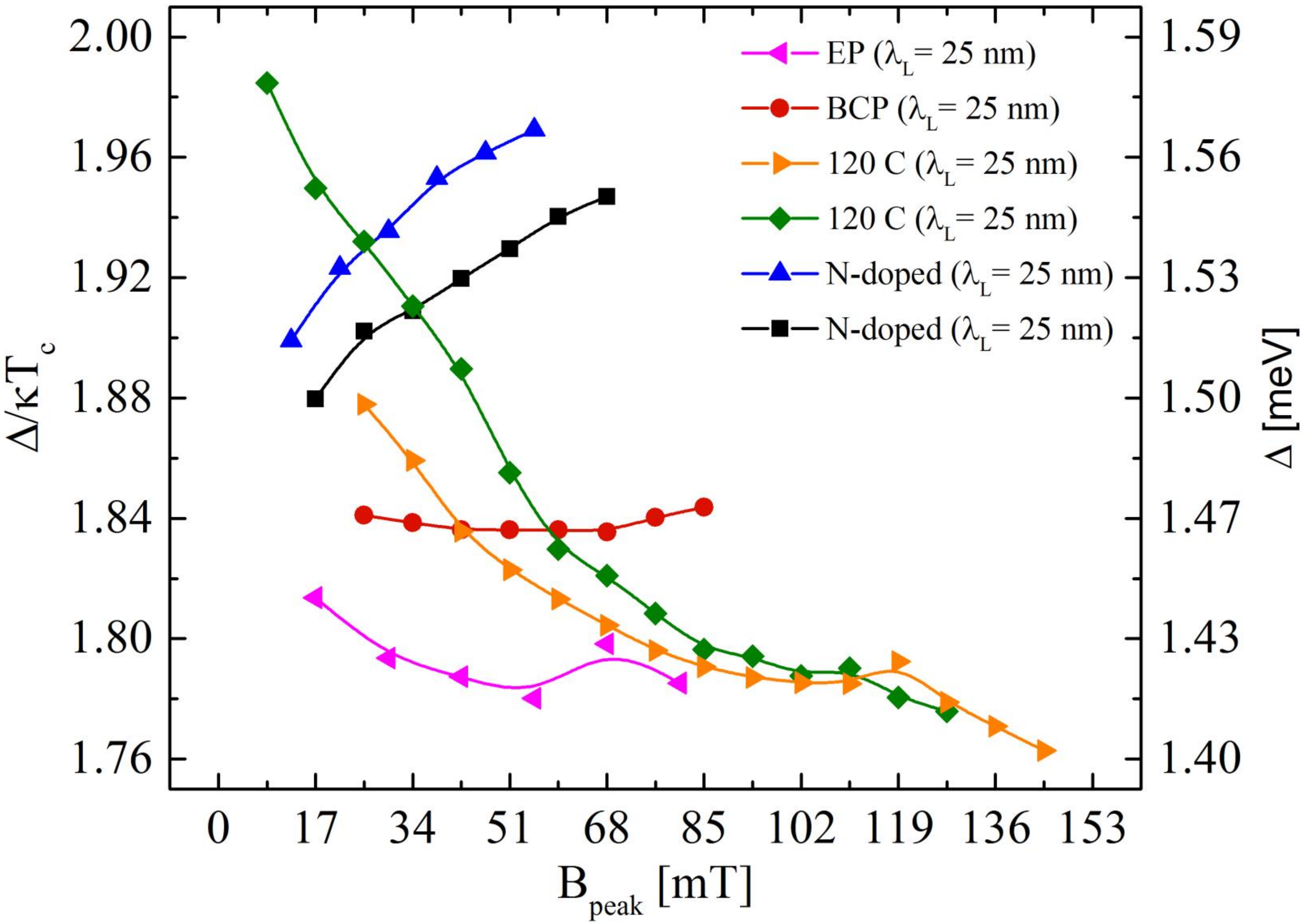

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- *Fixed parameters*:
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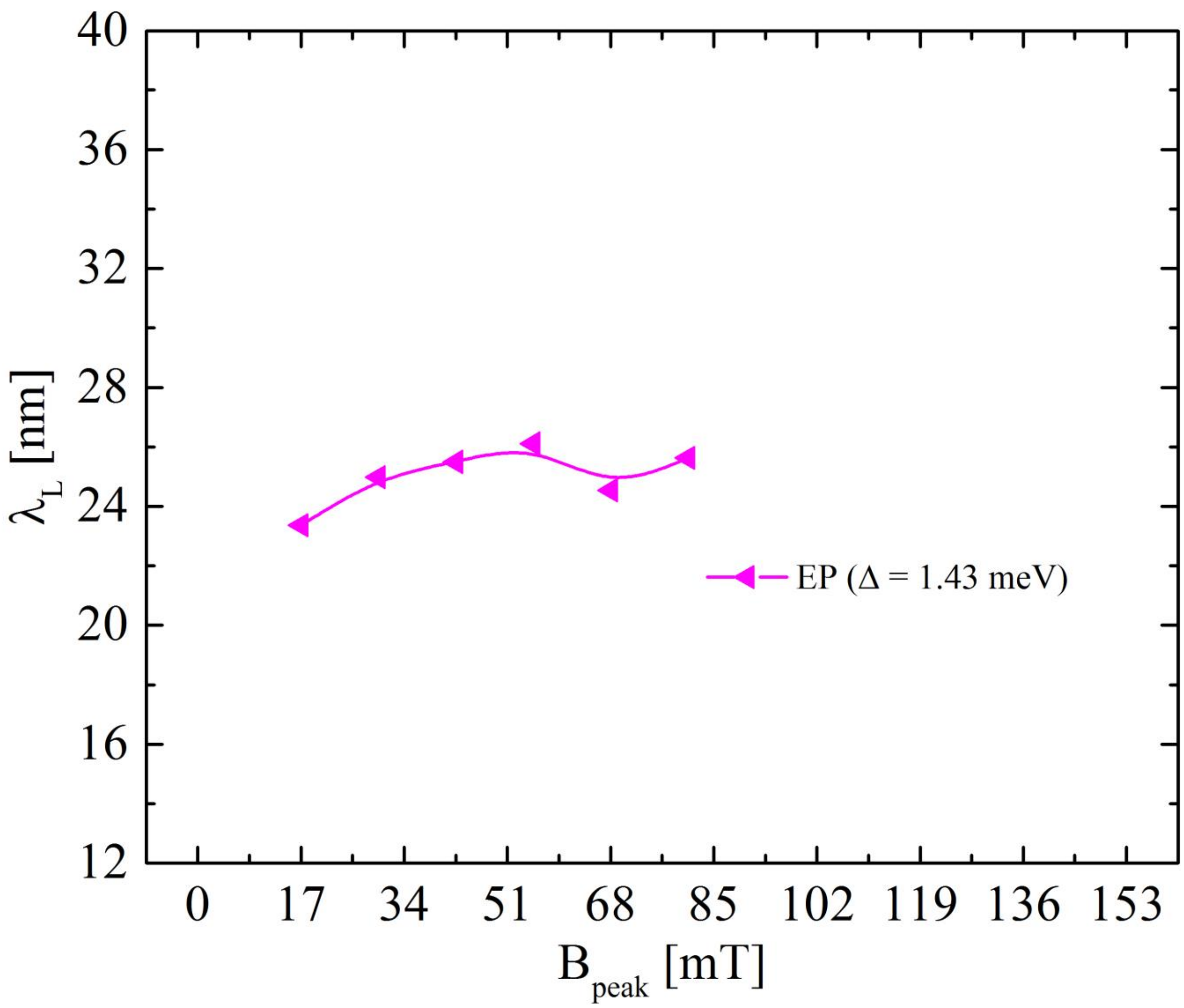
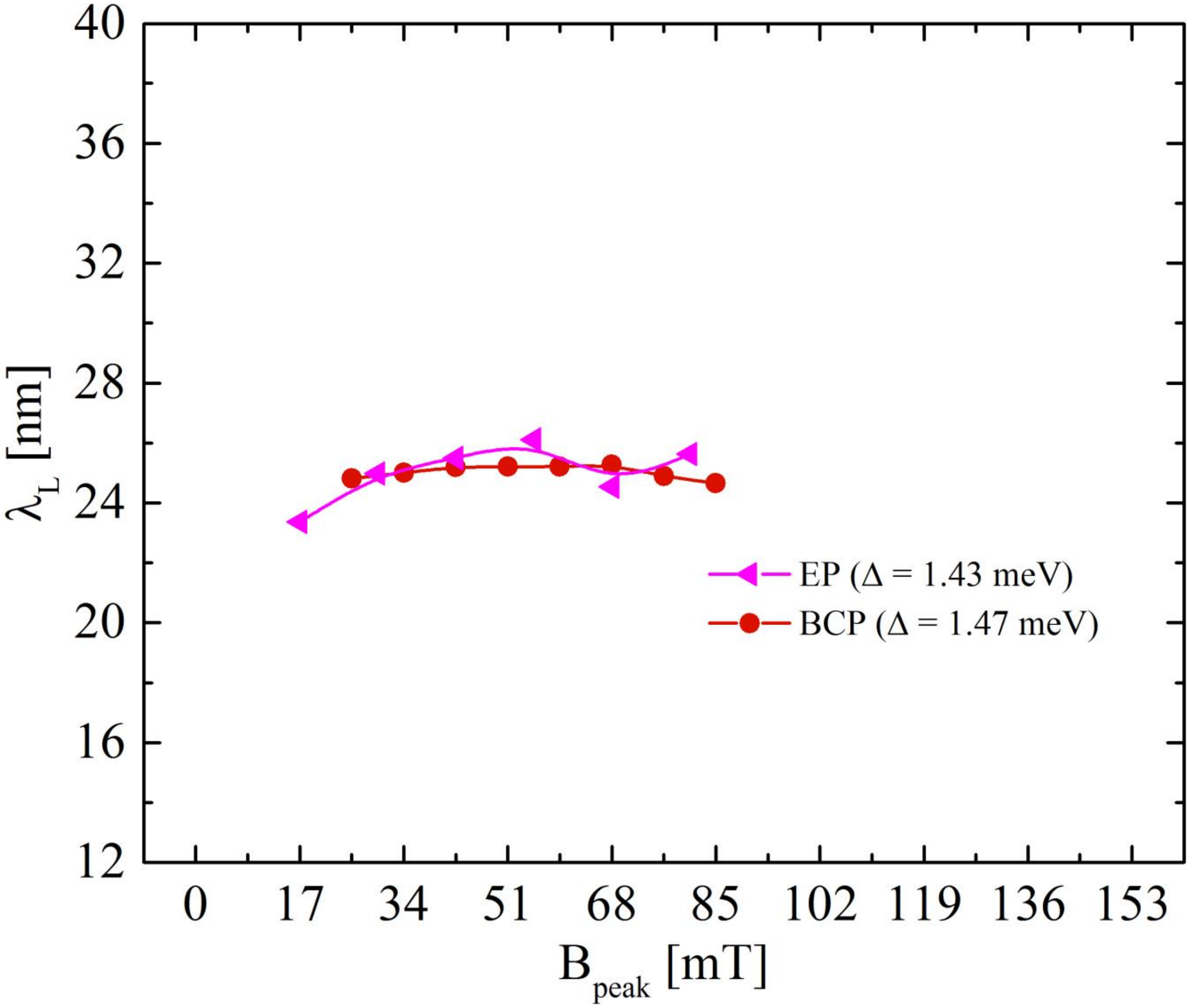
  $\longrightarrow$ l obtained from SRIMP code / Drude model / LE-μSR
  $\longrightarrow$ $\pi\xi_0/2 = 620$ Å

- *Free parameters*:
  $\longrightarrow$ λ_L
  $\longrightarrow$ R_0

λ_L as a function of field (fixed $\Delta/(\kappa T_c)$)



λ_L as a function of field (fixed $\Delta/(\kappa T_c)$)



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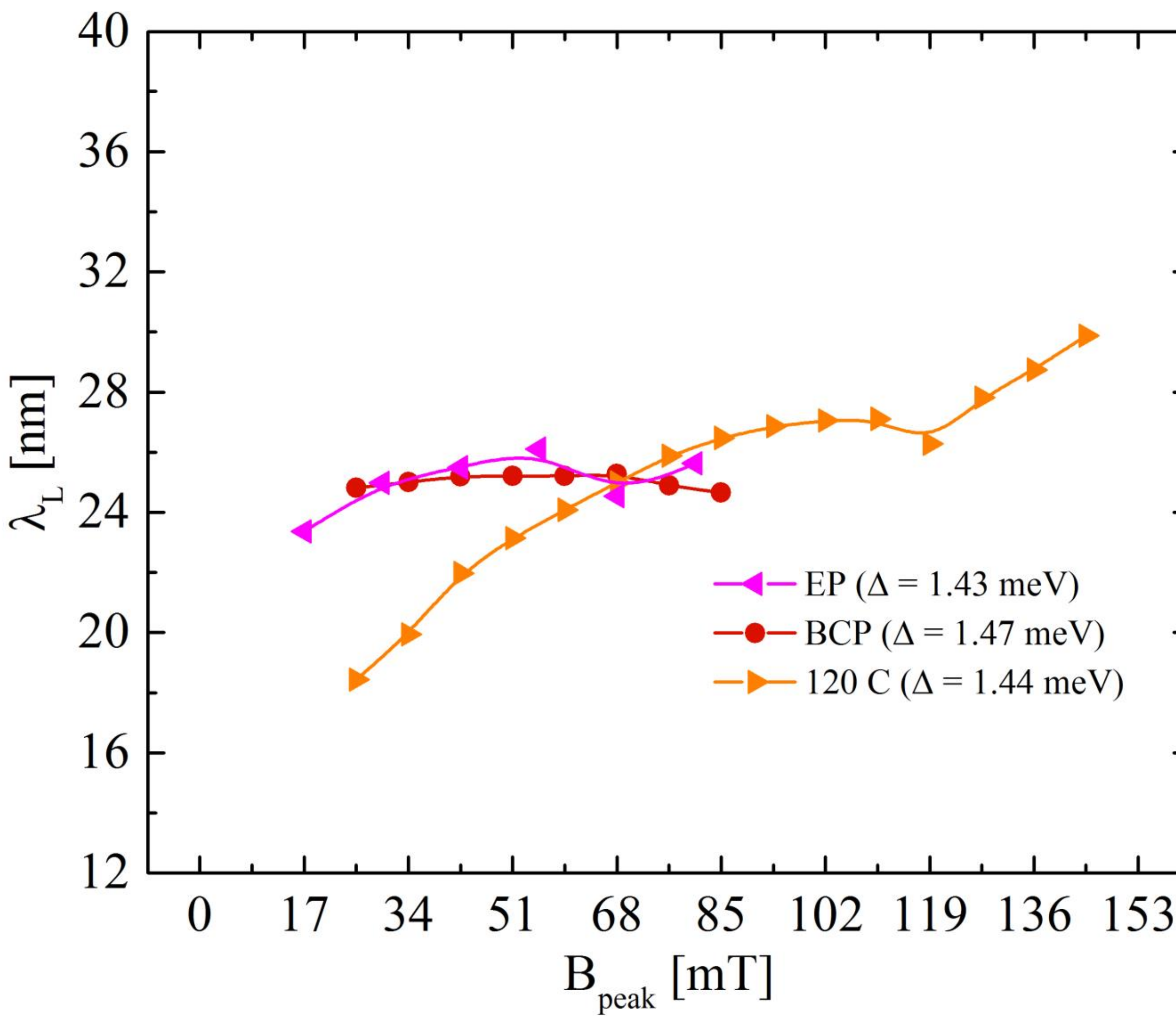

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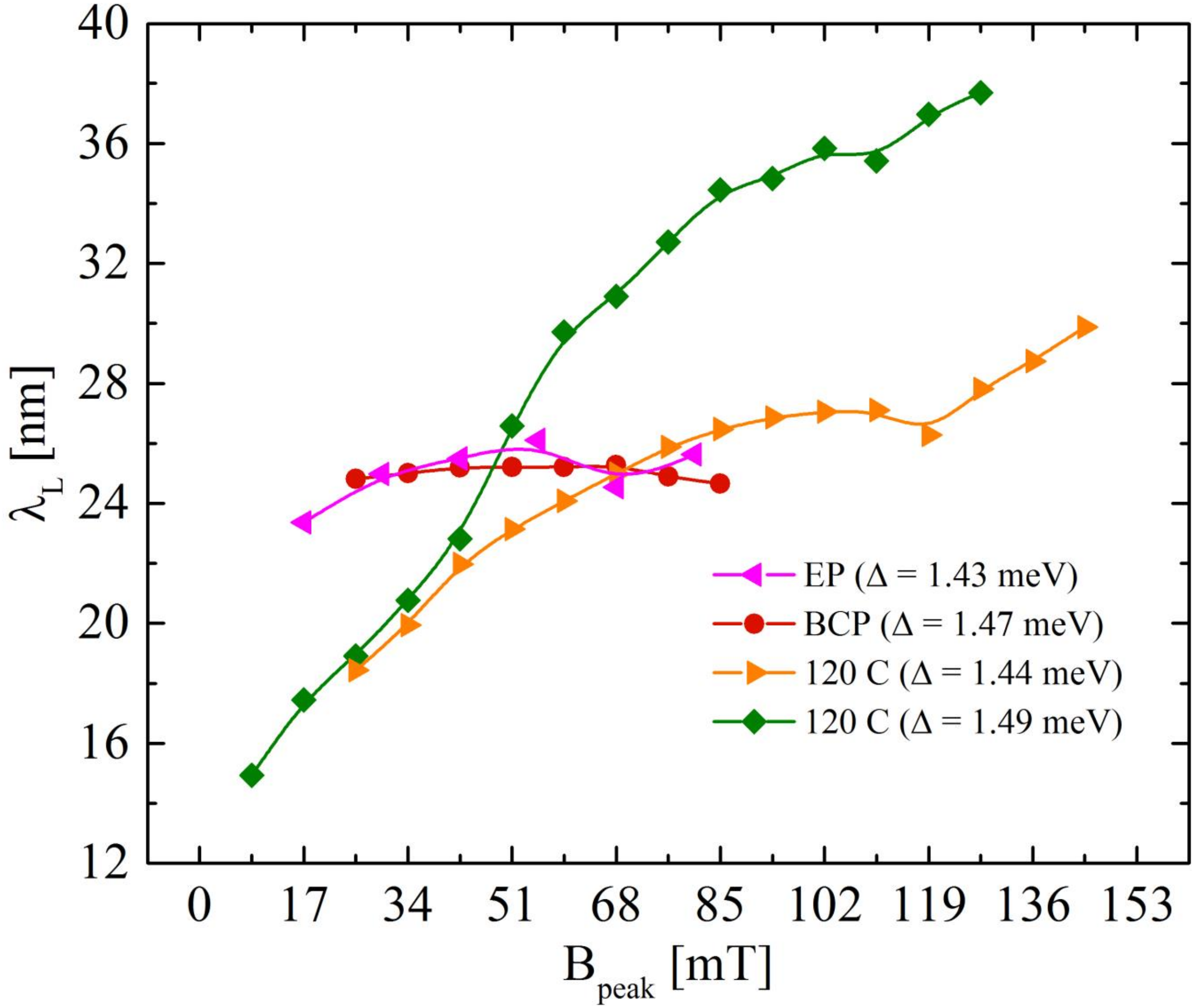

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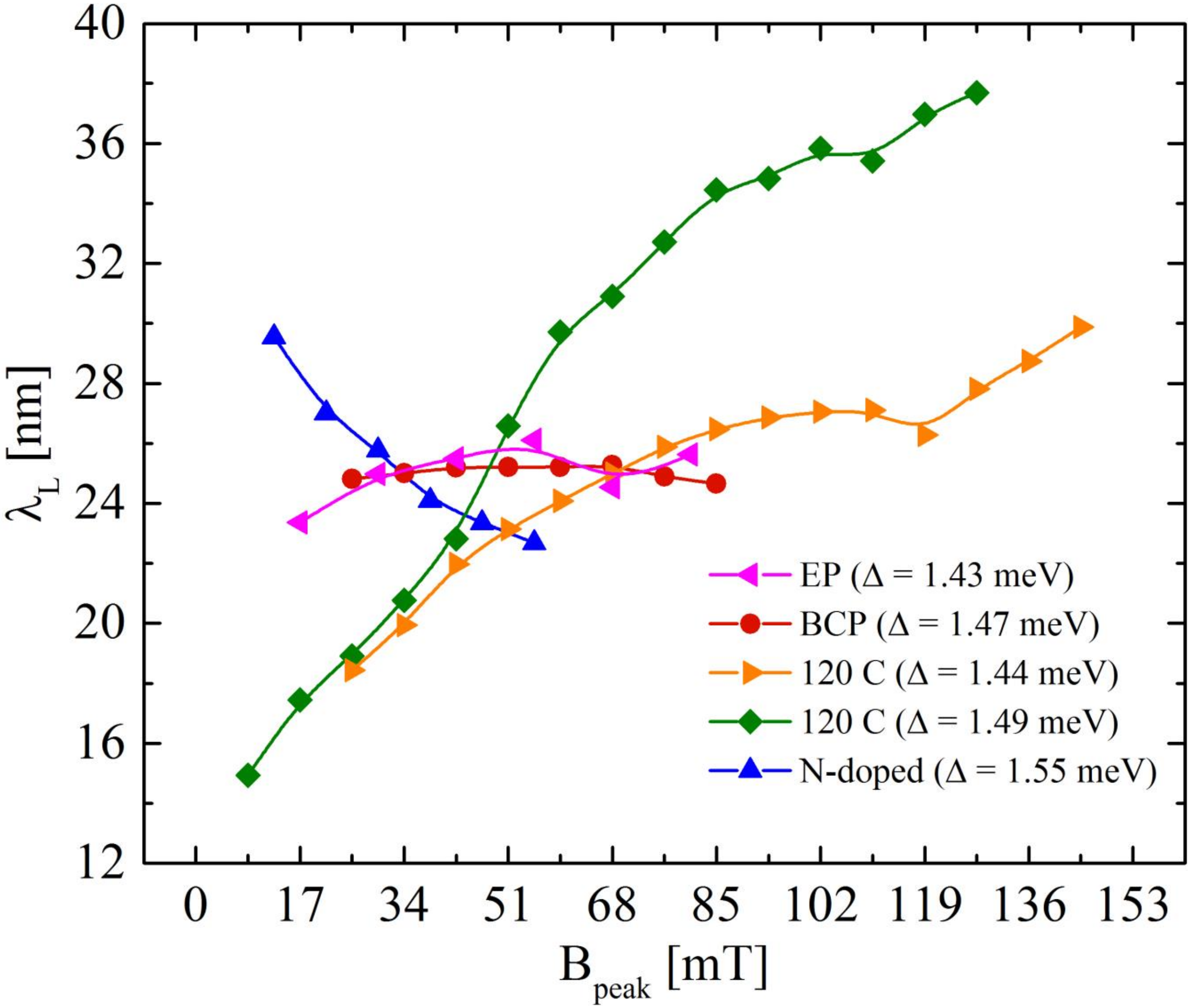
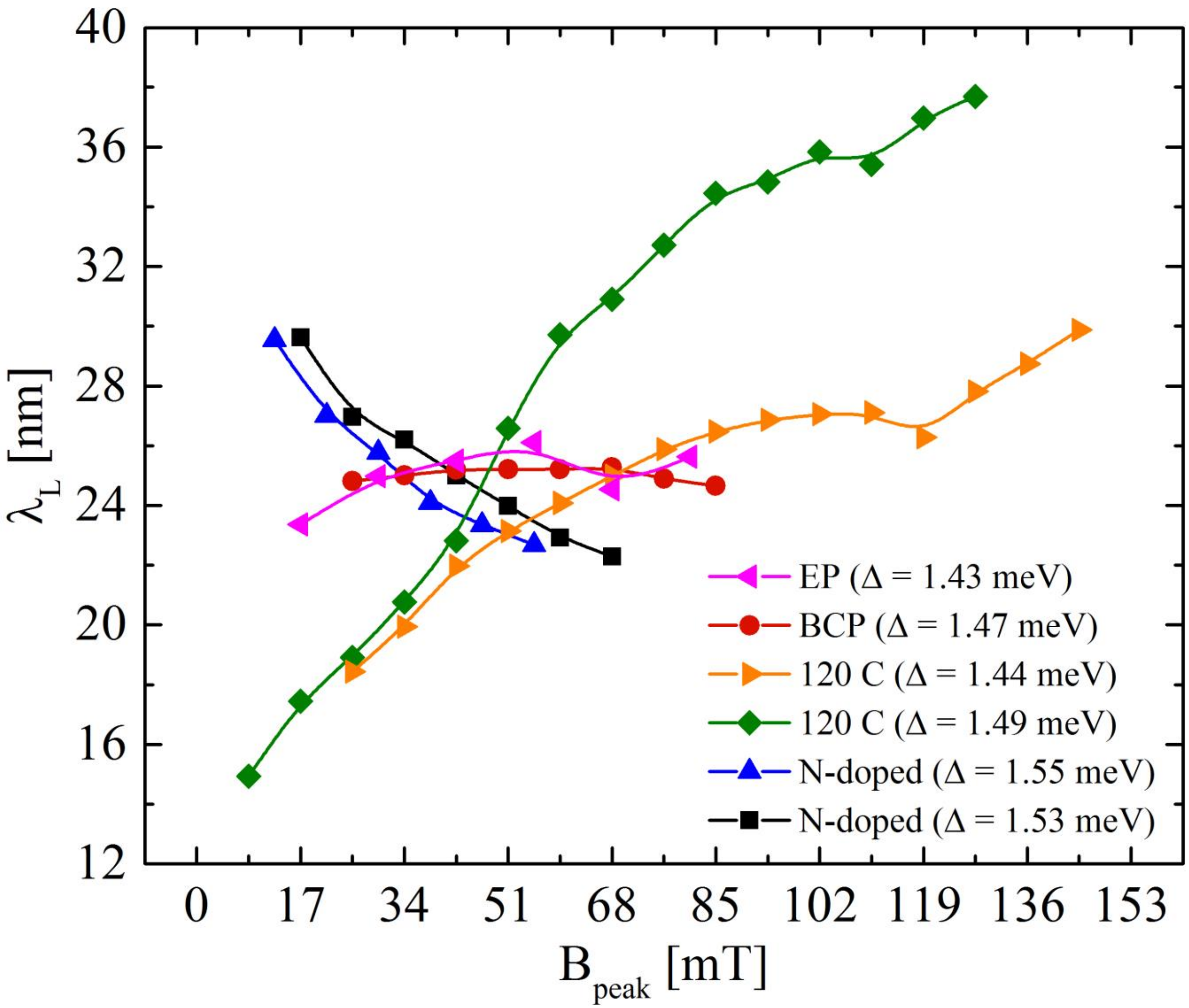


λ_L as a function of field (fixed $\Delta/(\kappa T_c)$)



Is it λ_L or Δ that is field dependent?

The decrement of R_{BCS} can be described both by the increment of Δ (exponential) or by the decrement of λ_L (pre-factor):

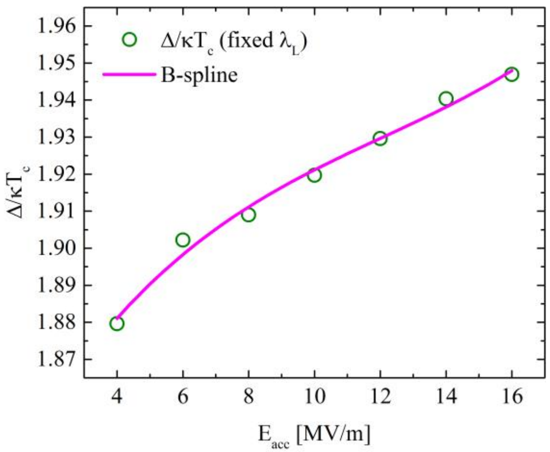
$$R_{BCS}(T) \propto A(\lambda_L, \xi_0, l) \cdot e^{-\frac{\Delta}{\kappa T}}$$

- By fitting R_s vs T both λ_L or Δ can be set as free parameter
- The correlation between λ_L and Δ is large (multiplication)
  $\rightarrow$ if λ_L is fixed, the field dependence of Δ might also account for the dependency of λ_L, and vice versa!

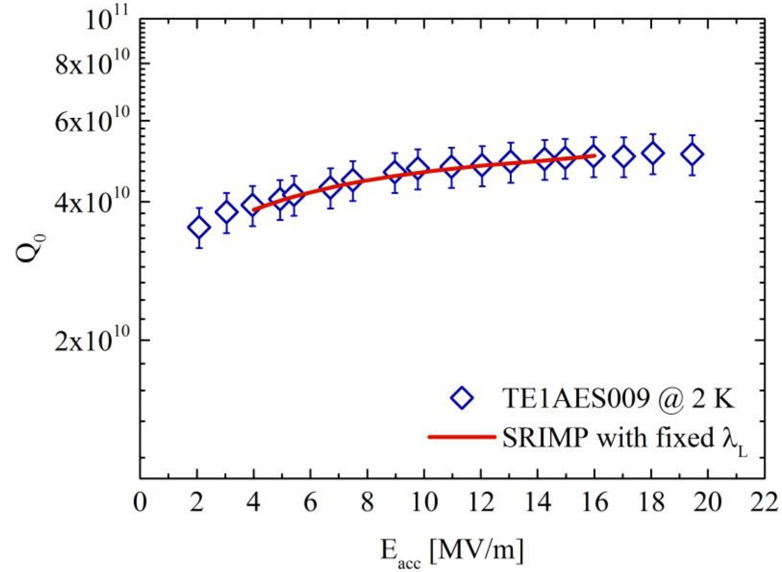
We cannot discriminate whether it is λ_L or Δ that is varying!

Both parameters can well describe the RF data!

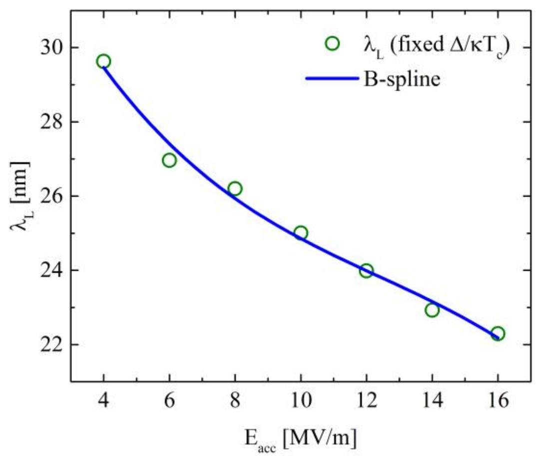
› Fixed λ_L:



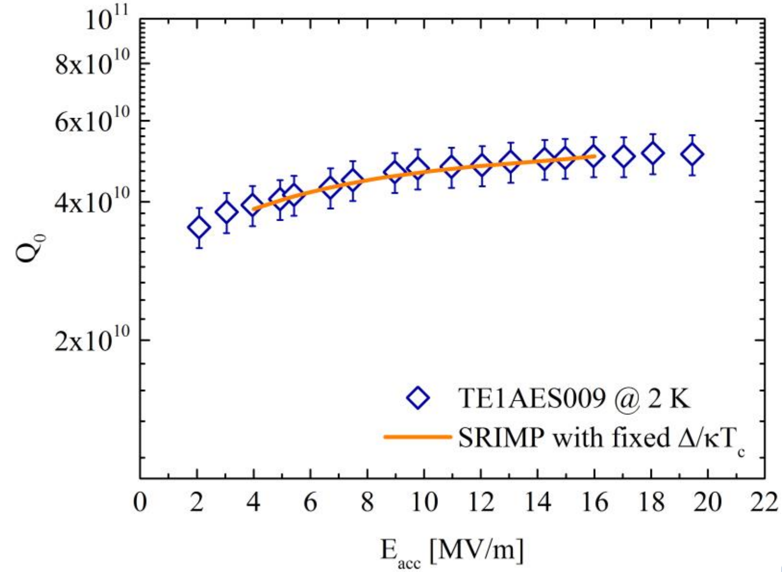
SRIMP



› Fixed $\Delta/\kappa T_c$:



SRIMP



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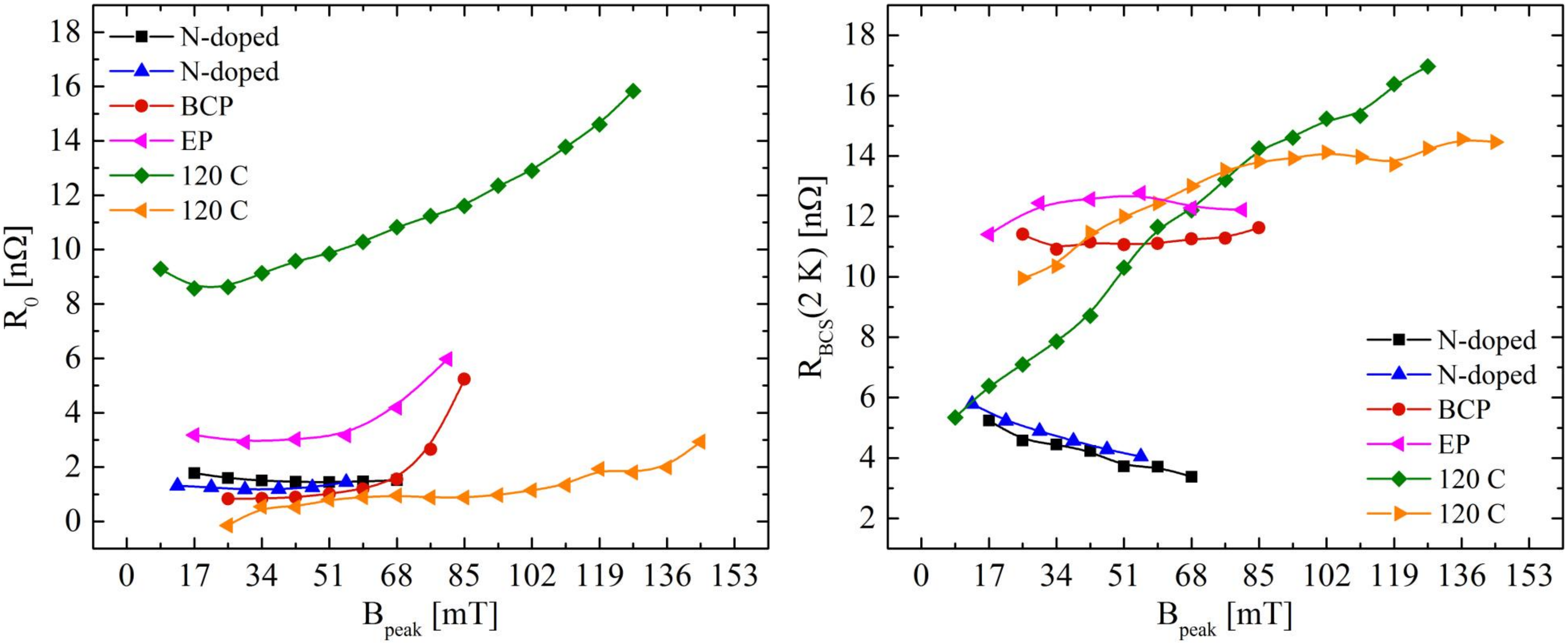
R_s decomposition

$\langle R_0 \rangle$ was calculated as the average of R_0 extrapolated with λ_L fixed and $^{\Delta}/_{\kappa T_c}$ fixed. Then $R_{BCS}(2\ K)$ is:

$$R_{BCS}(2\ K) = R_s(2\ K) - \langle R_0 \rangle$$



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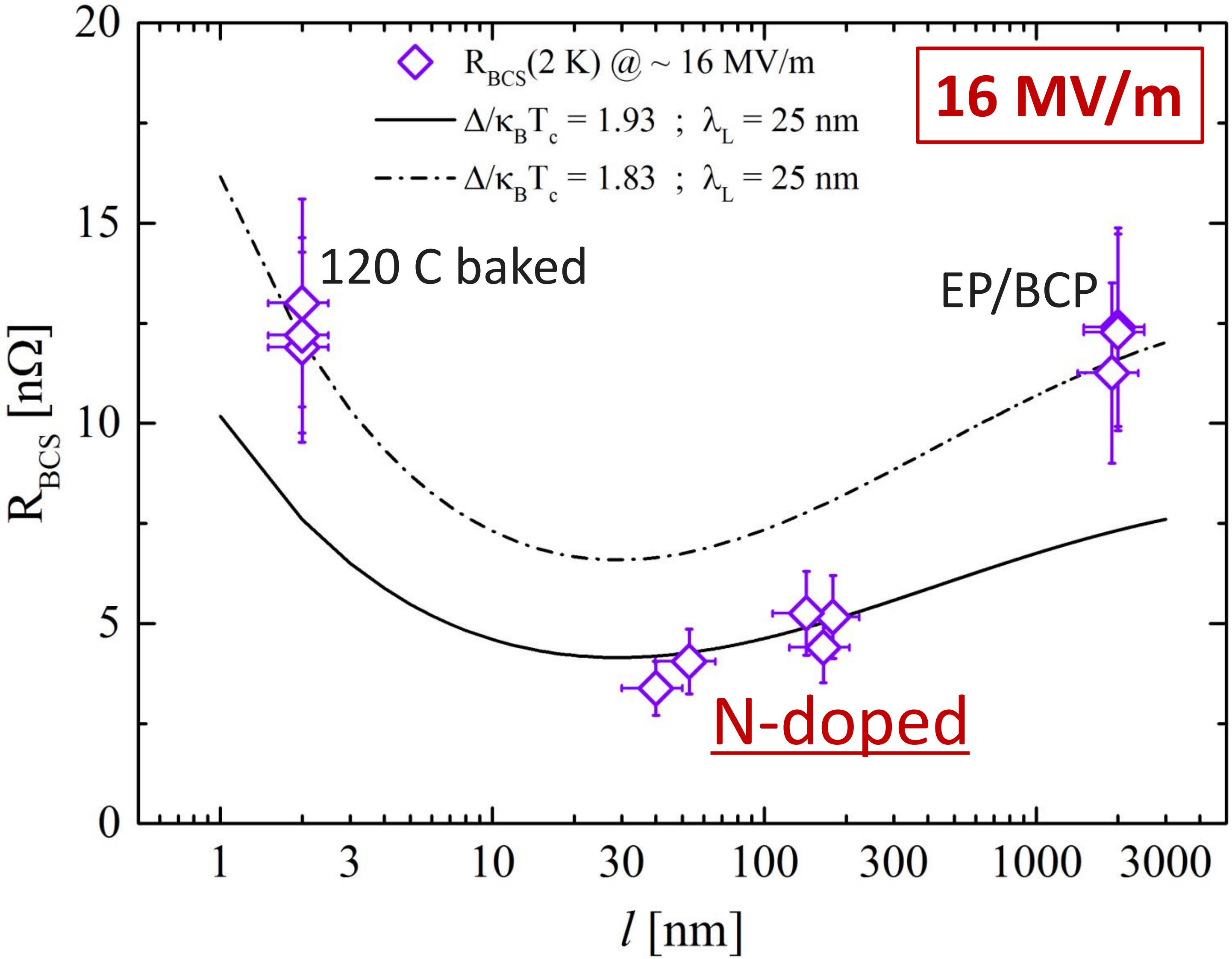
$R_{BCS}(2K)$ as a function of mean free path



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General conclusions

- With such approach we can obtain quantitative information about R_0 and R_{BCS}, but only qualitative information of all the SC parameters

- Fixed λ_L:
  - N-doped: Δ increases with the field
  - 120 C baked: Δ decreases with the field
  - EP/BCP: Δ seems constant

- Fixed Δ:
  - N-doped: λ_L decreases with the field
  - 120 C baked: λ_L increases with the field
  - EP/BCP: λ_L seems constant

N-doped cavities conclusions

- Both the variations of λ_L or Δ with the field can well describe the anti-Q-slope
  - $\longrightarrow$ We cannot conclude that only λ_L or Δ is field dependent
  - $\longrightarrow$ More probably, the whole superconducting behavior of the cavity is enhanced with the field
  - $\longrightarrow$ But, <u>why only if N-doped</u>?

- The N-doped cavities BCS resistances as a function of the mean free path fall next to the minimum of the theoretical curve
  - $\longrightarrow$ Cavities with different thermal treatments follows different curves: Δ changes with the treatment
  - $\longrightarrow$ N-doped cavities have larger gap at medium field

Thank you