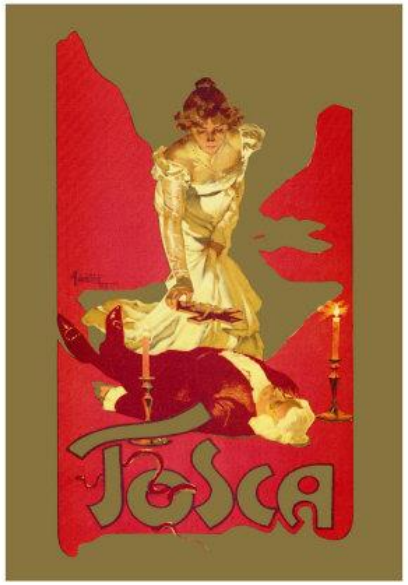
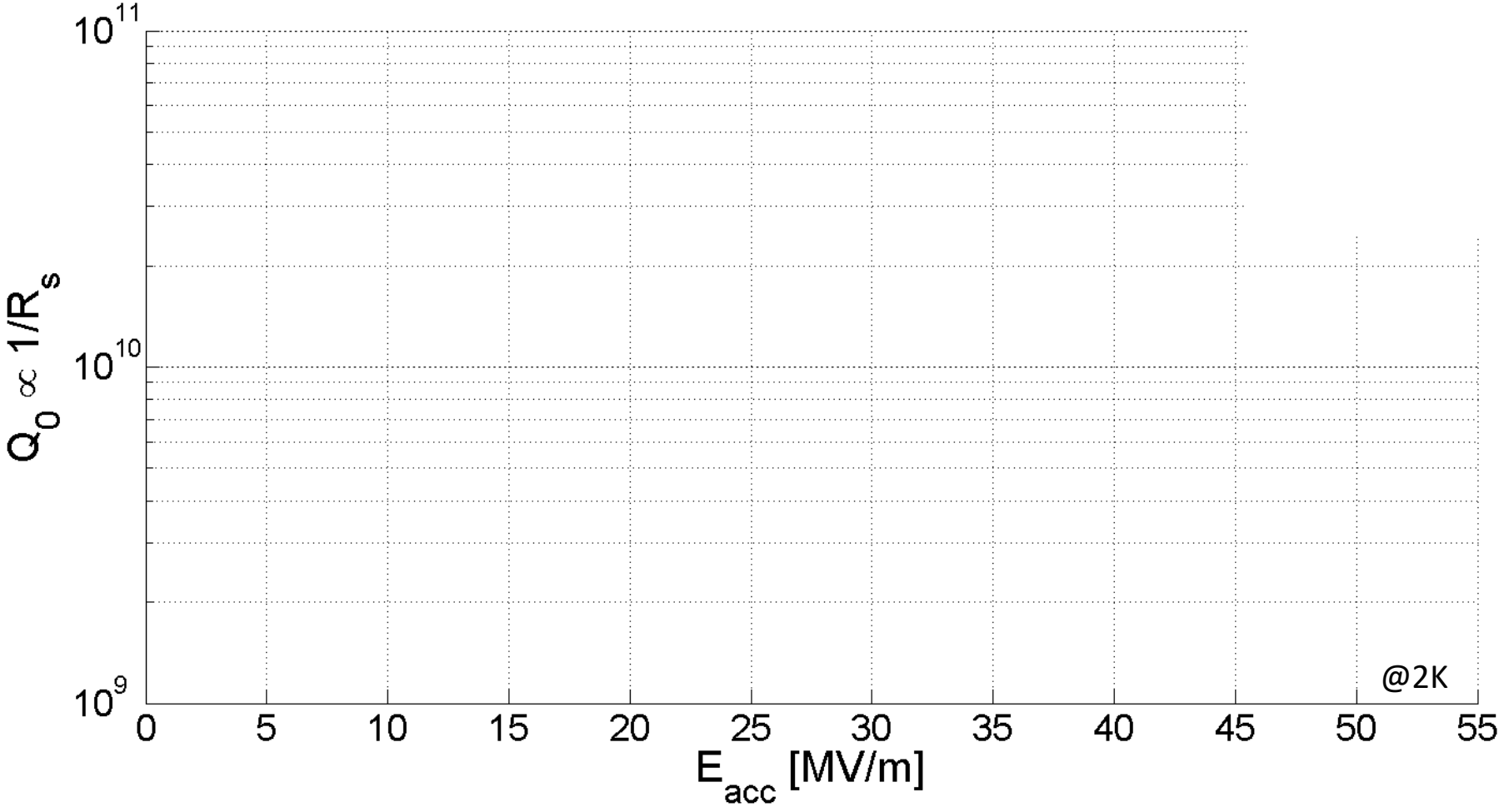
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Interstitial oxygen tailoring by various surface treatments and how it impacts Q_0



Rezvan Ghanbari, Artem Zaidman, Marc Wenskat
– on behalf of the UHH SRF R&D Team

Recipes to choose from



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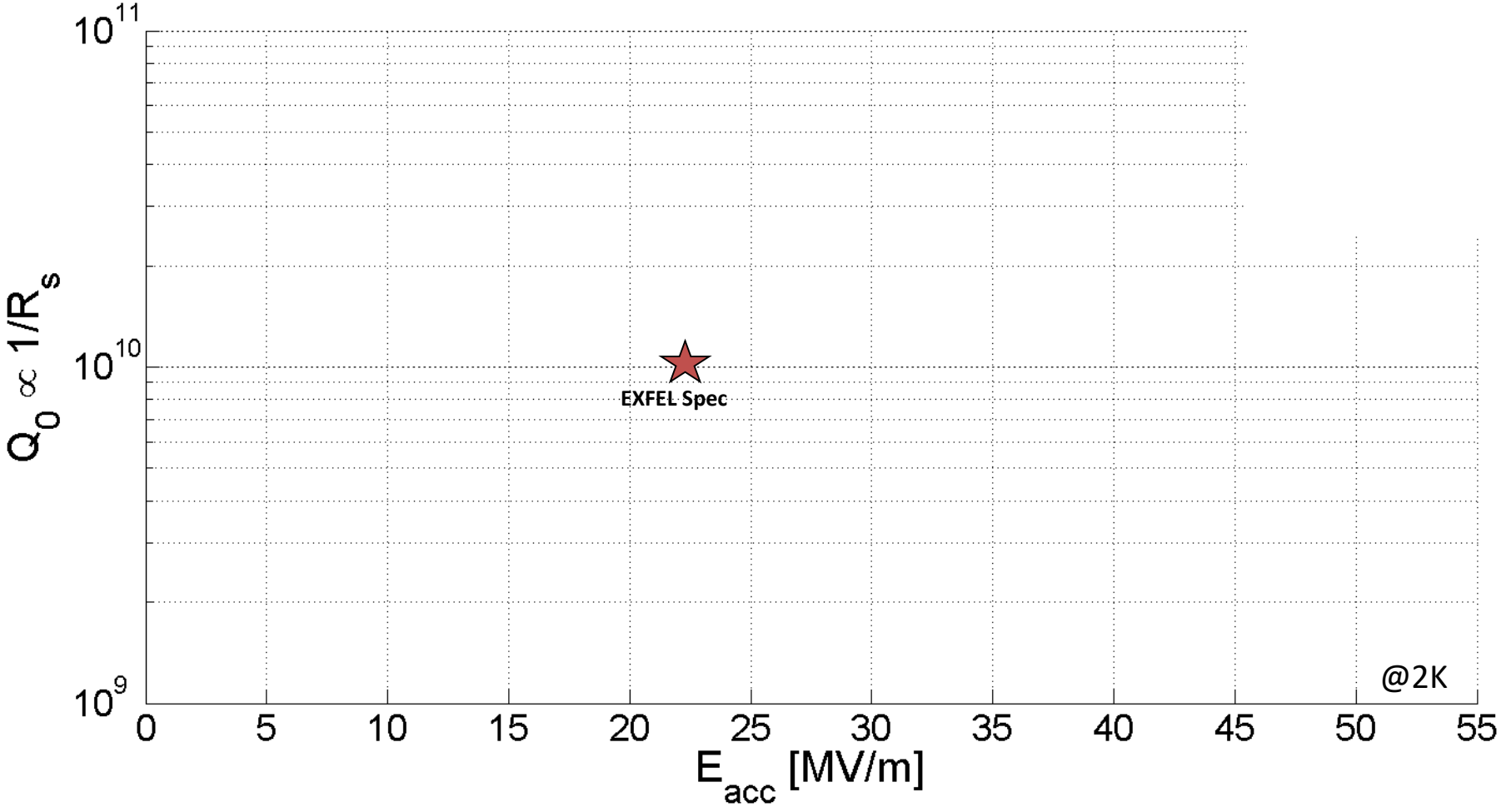

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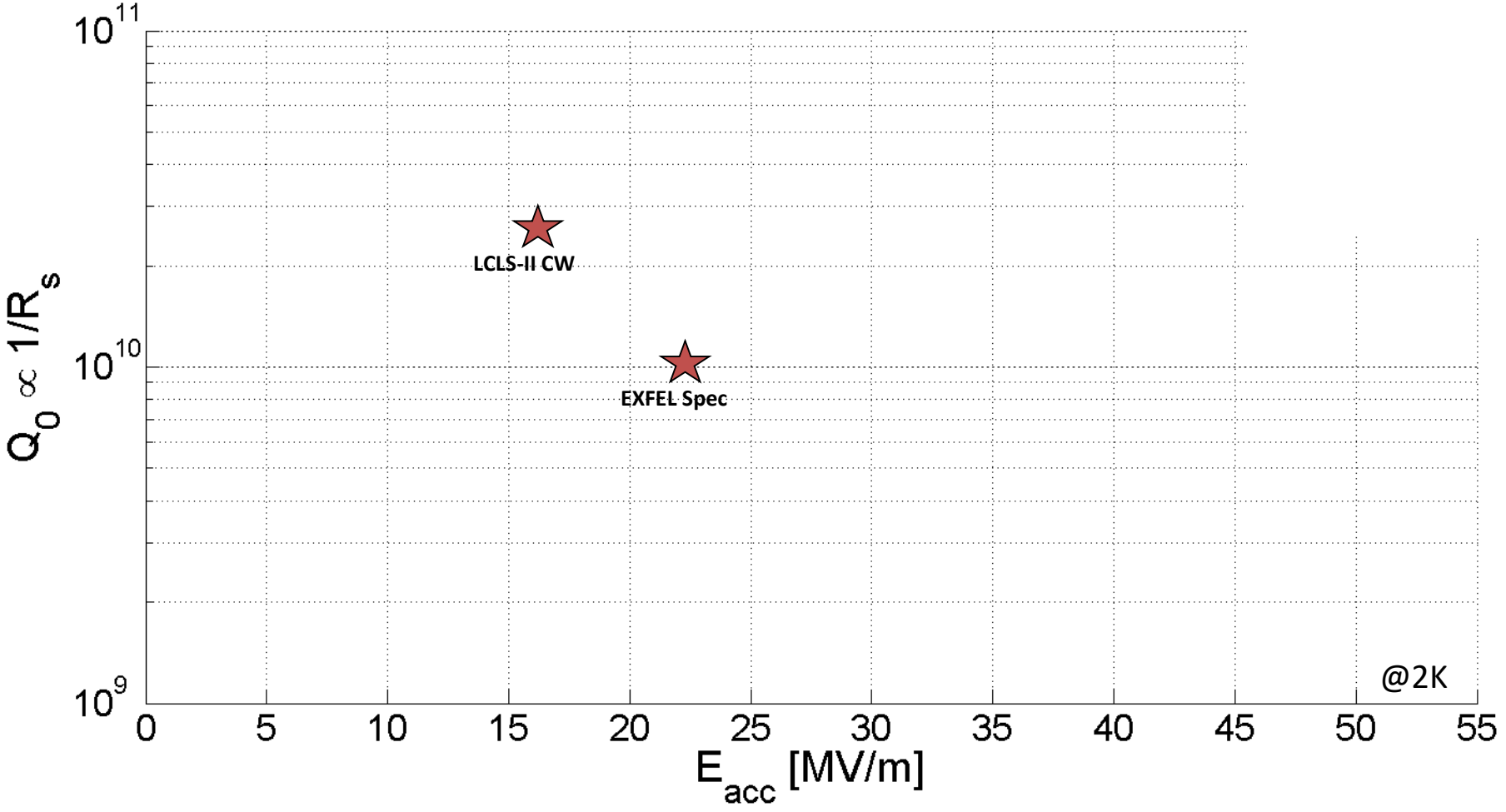

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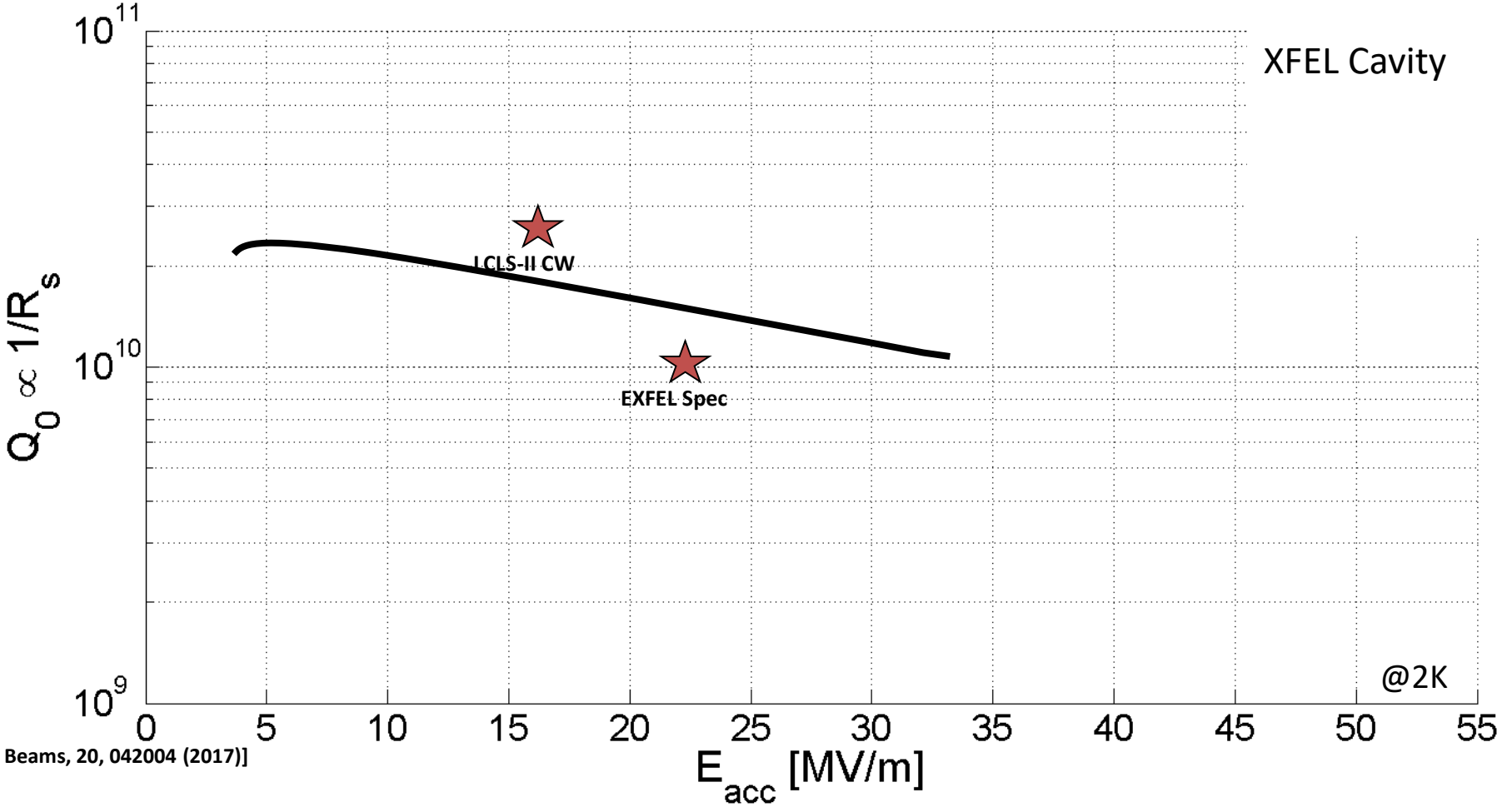

[Reschke et al., Phys. Rev. Accel. Beams, 20, 042004 (2017)]

Cavities limited by quench

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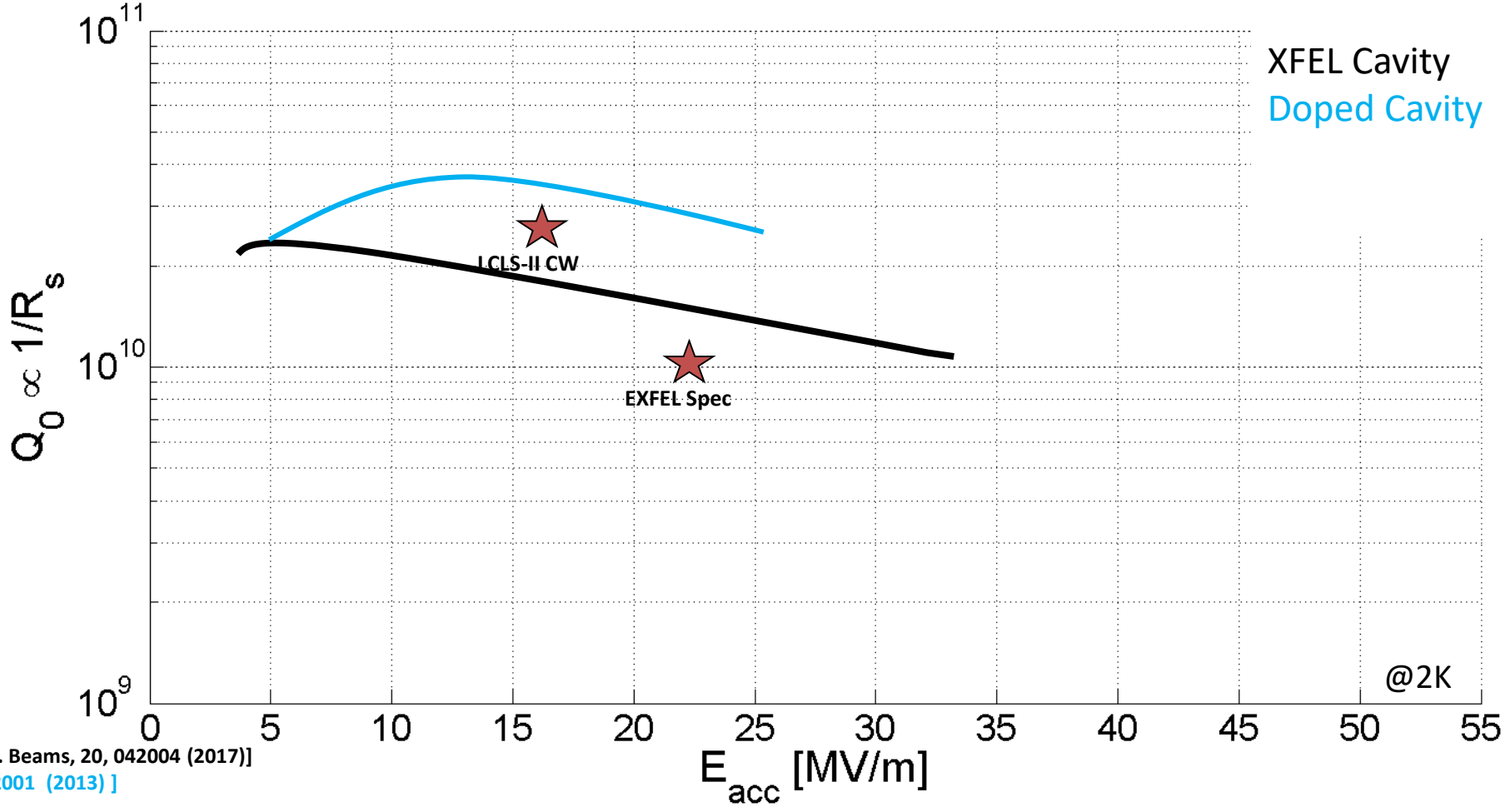

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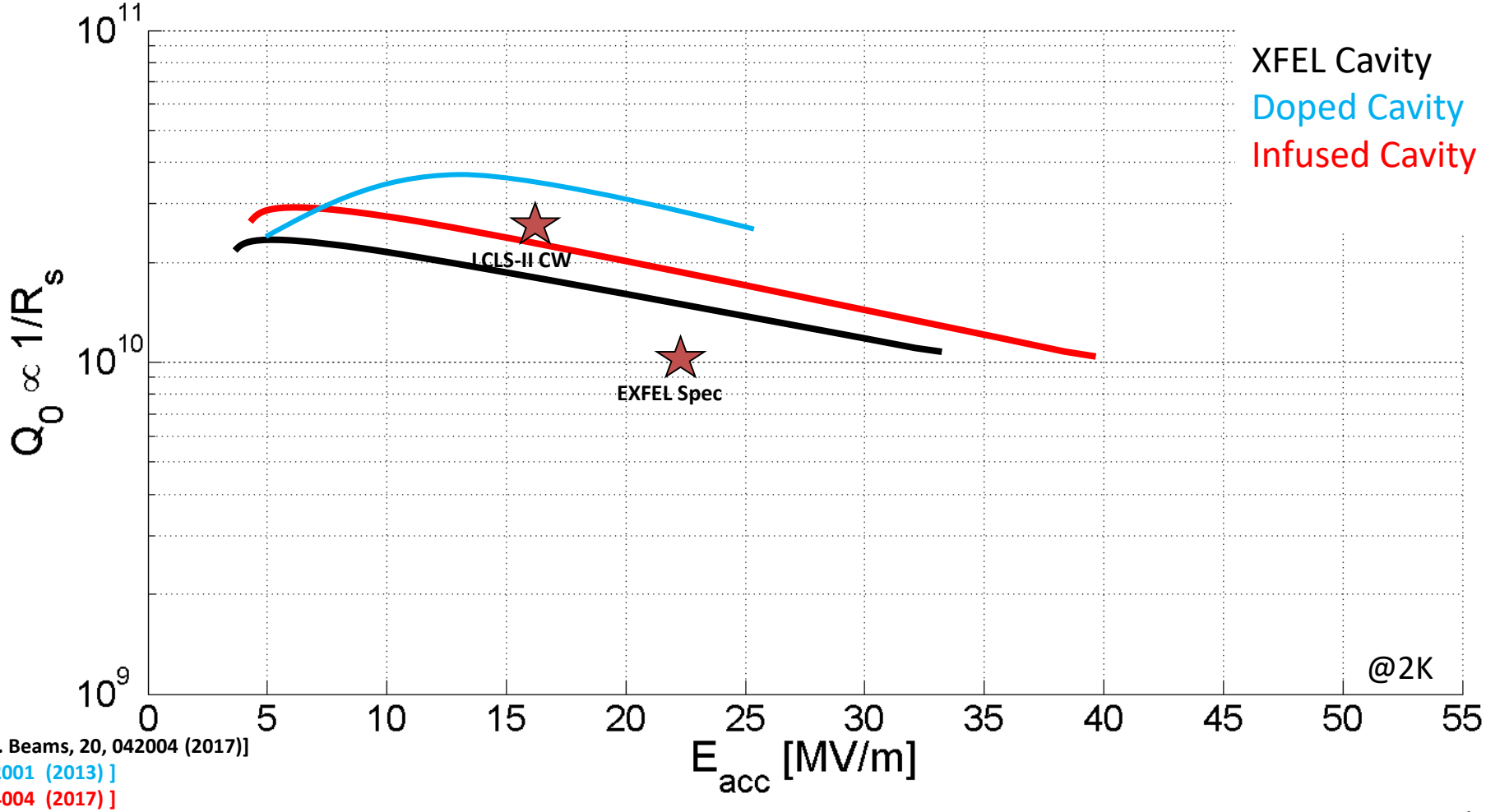

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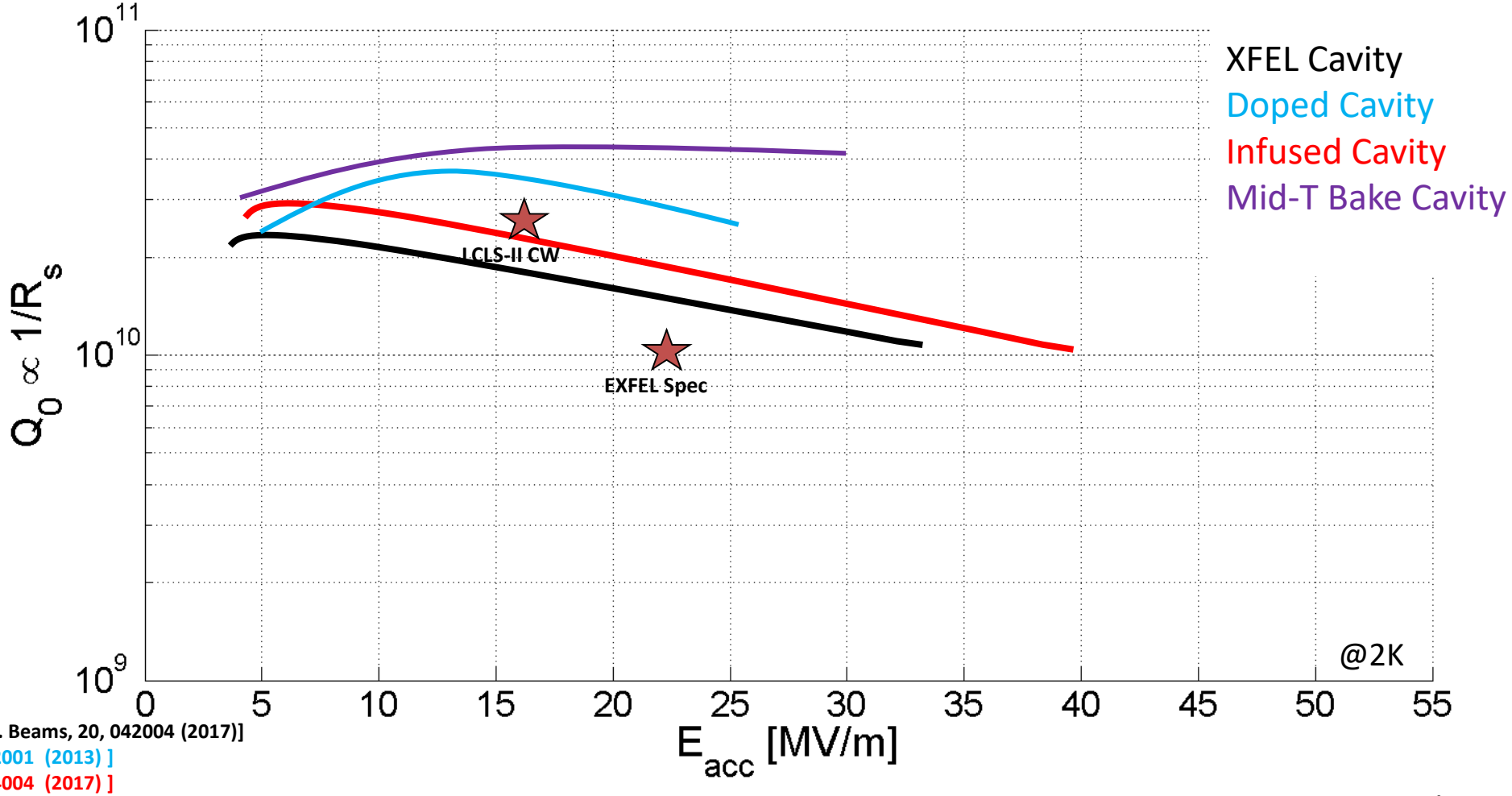

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[Grassellino et al., SUST, 26, 102001 (2013)]
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[Posen et al., Phys. Rev. Applied 13, 014024 (2020)]

Cavities limited by quench

What happens during Mid-T Bake?

Mid-T Bake:
T: 300°C – 400°C
t ≈ 3-20h
$p \leq 10^{-6}$ mbar

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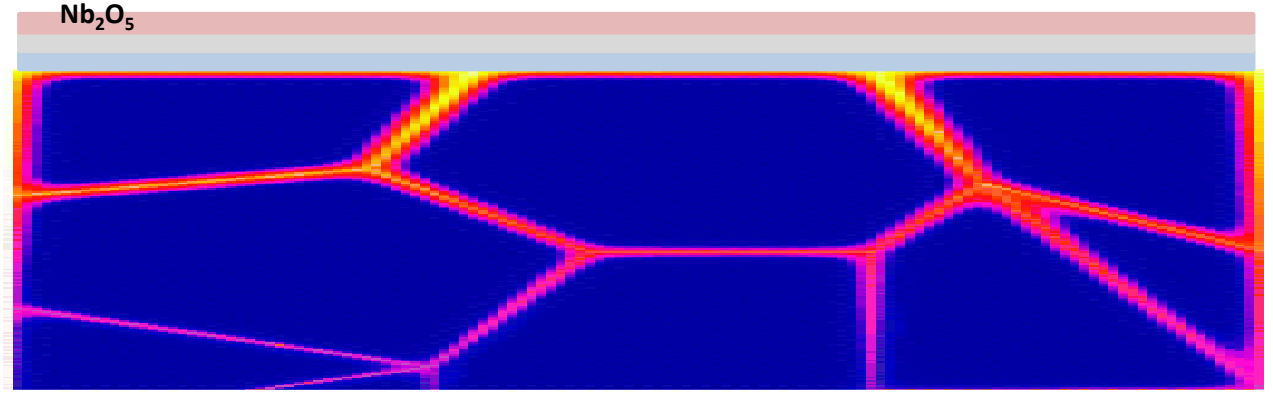
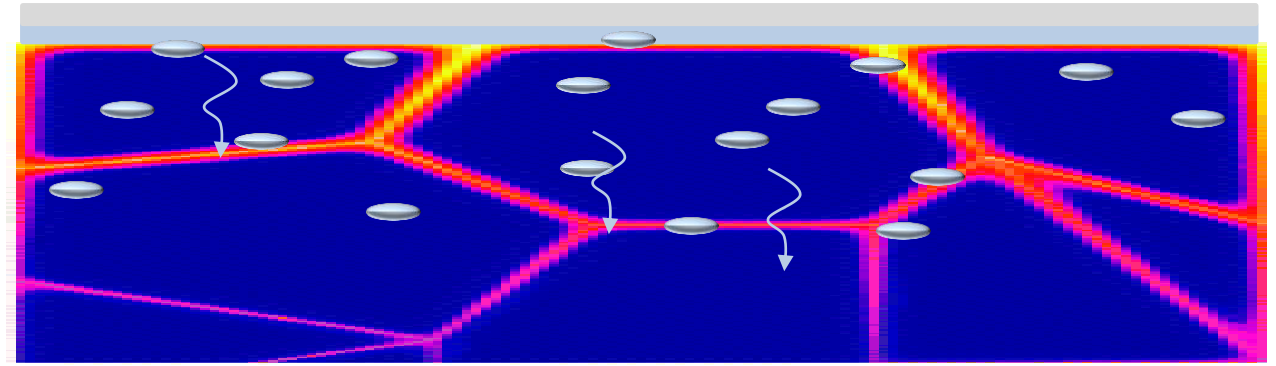


What happens during Mid-T Bake?

Mid-T Bake:
T: 300°C – 400°C
t ≈ 3-20h
p ≤ 10^{-6} mbar

Nb_2O_5 dissolves around ≈250°C



Oxygen

Failed HPR showed unwanted oxide growth

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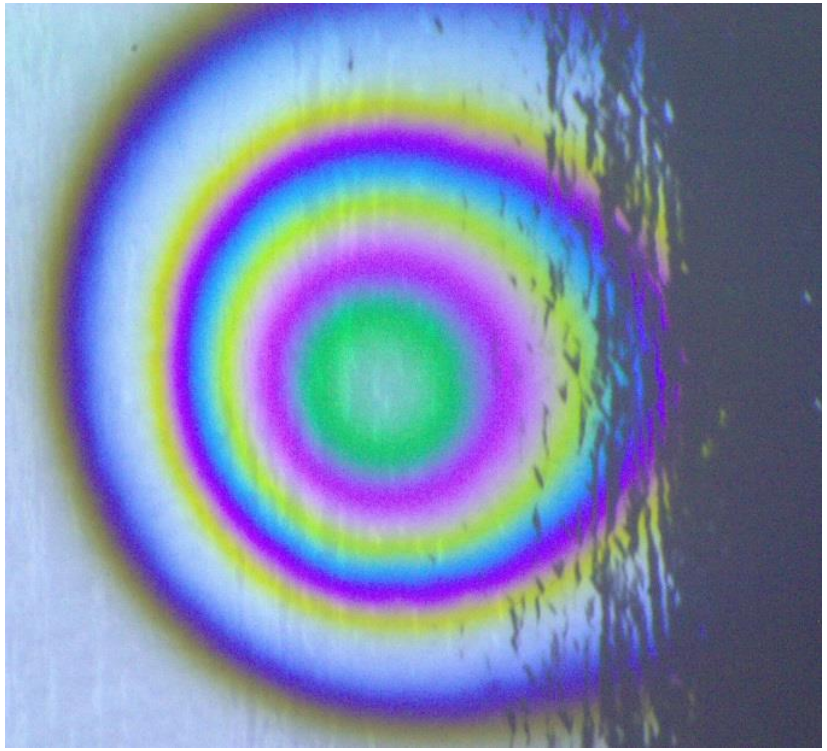
In two cases HPR on cavities created rainbowspots
(AC126, NXPKU5)



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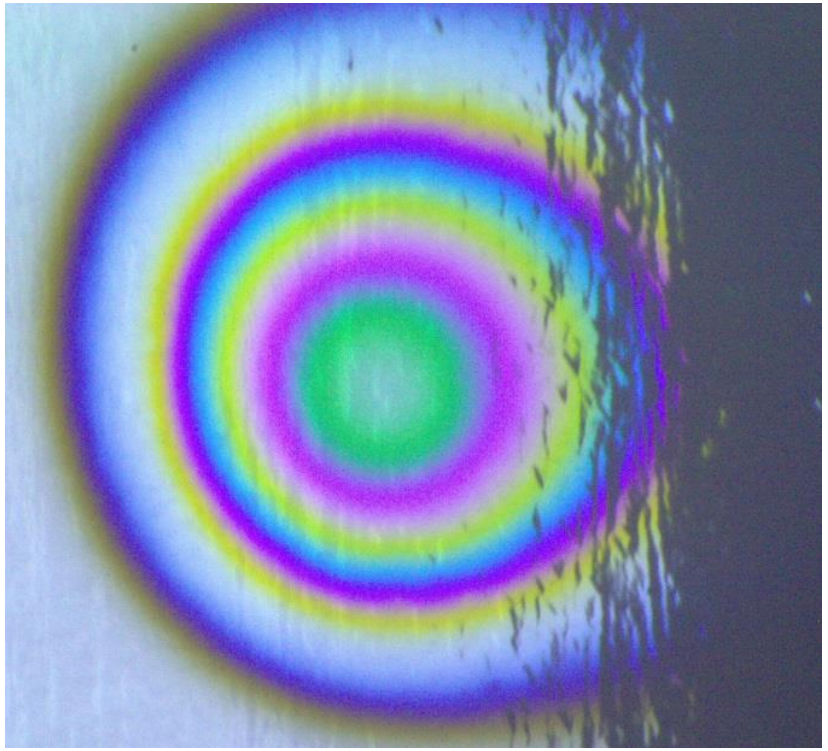
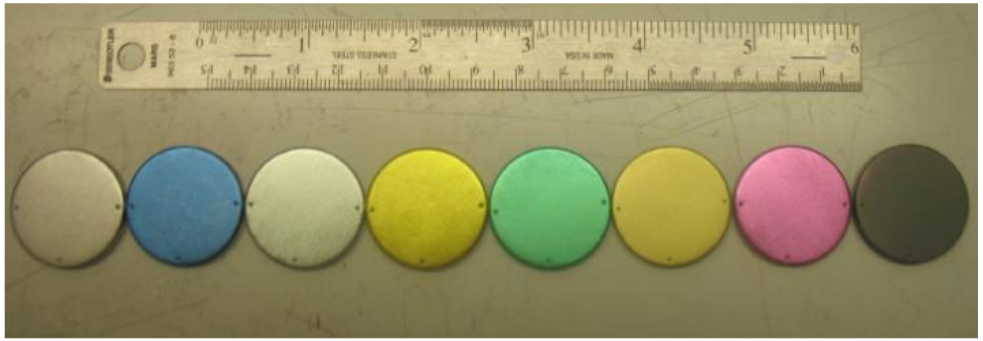


[Wu, A. T., et al. *Effects of the thickness of niobium surface oxide layers on field emission*. IPAC 2018 - MOPC118]



Sample	1	2	3	4	5	6	7
Voltage (V)	25	37	45	80	95	110	230
Color	Blue	Cyan	Bright Yellow	Green	Yellow	Red	Dark Grey
Oxide Thickness (nm)	53	77	93	163	193	223	463

Obvious pentoxide growth due to failed HPR

Extensive HPR

[Ghanbari, R. TTC Workshop 2022, Aomori]

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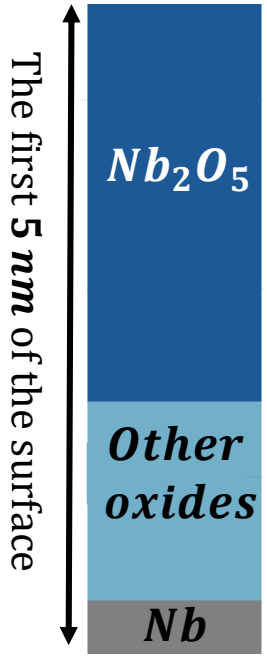
X-Ray Photoelectron Spectroscopy (XPS)

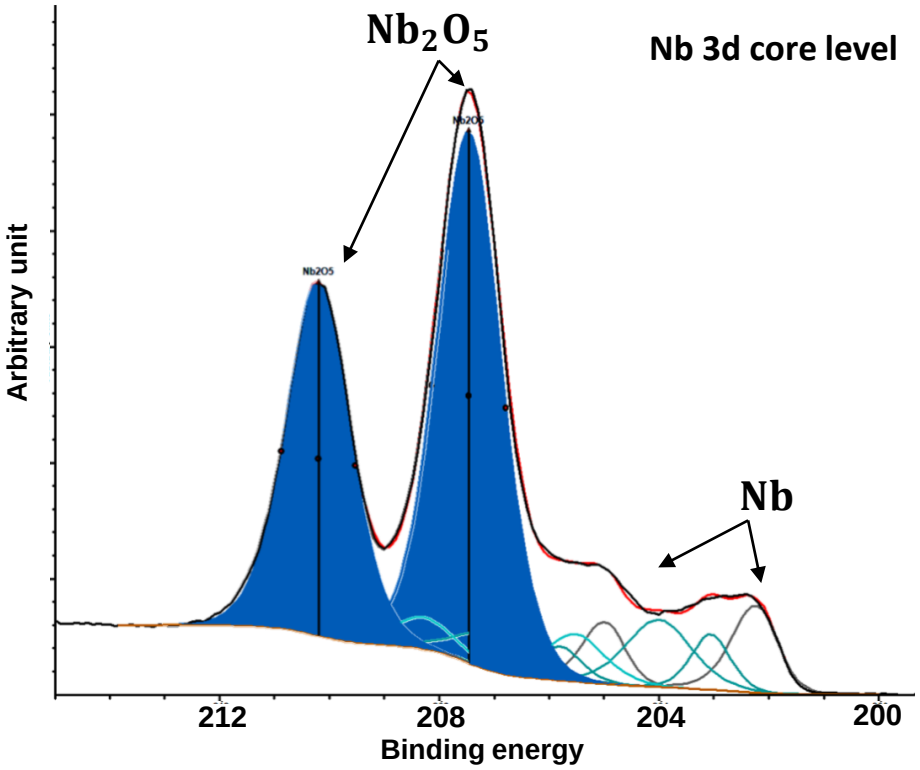
Reference 0 HPR cycle	Standard recipe 6 HPR cycles	18 HPR cycles

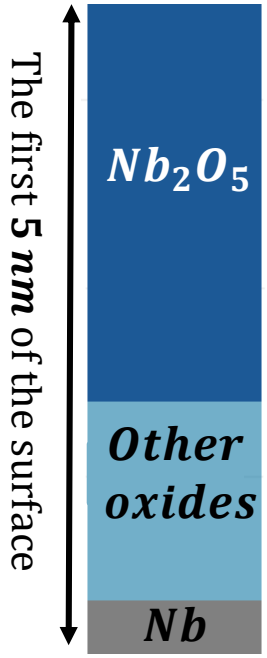


Extensive HPR

[Ghanbari, R. TTC Workshop 2022, Aomori]

$$\frac{\text{component doublet peaks area}}{\text{total Nb 3d peak area}}$$





X-Ray Photoelectron Spectroscopy (XPS)

Reference	Standard recipe	18 HPR cycles
0 HPR cycle	6 HPR cycles	

Extensive HPR → thicker Nb_2O_5

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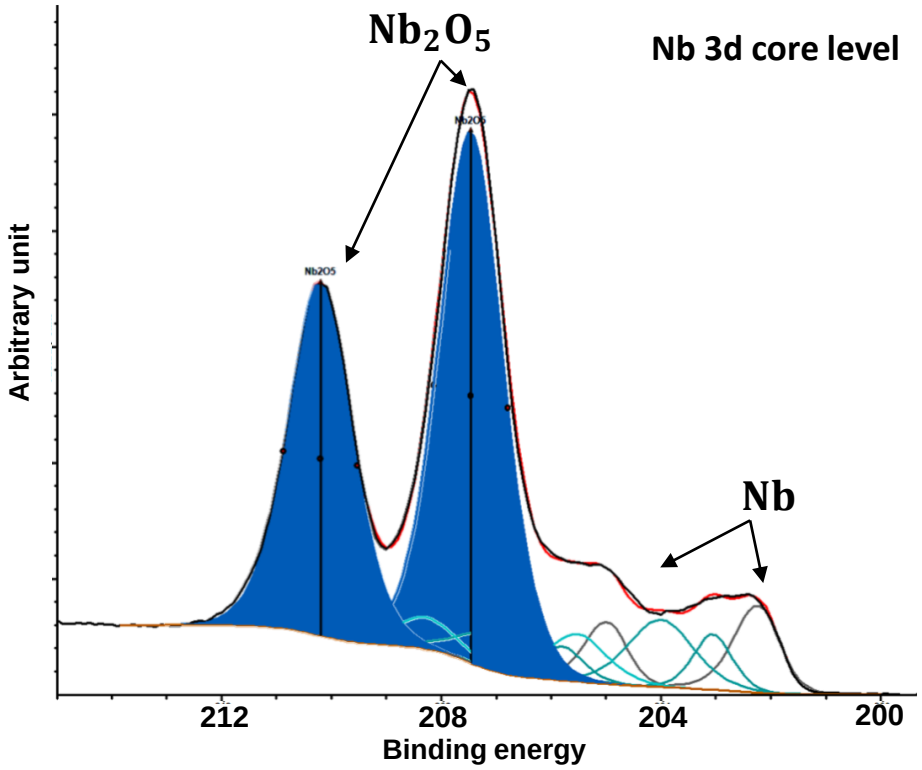

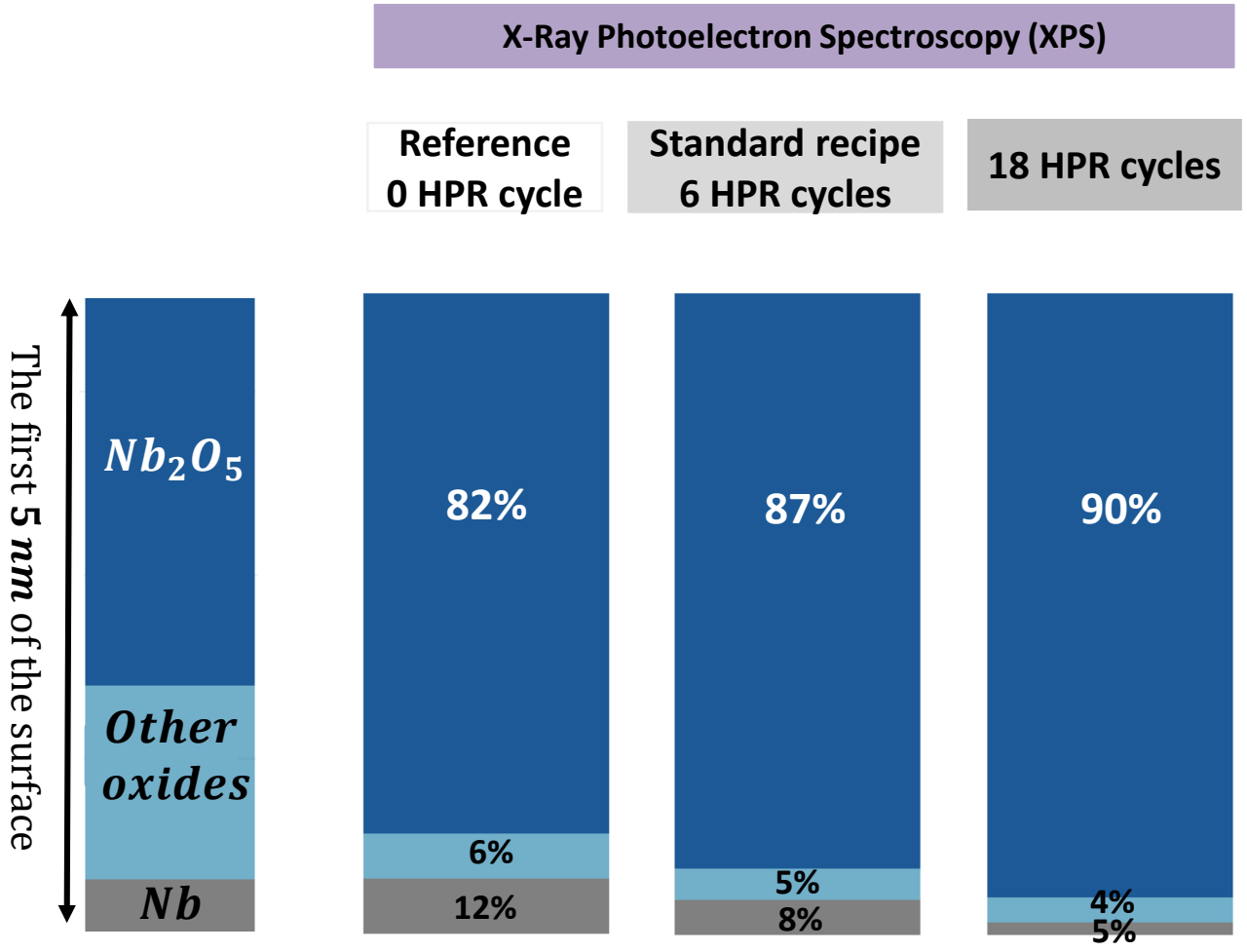

Extensive HPR → thicker Nb_2O_5 → more O for mid-T

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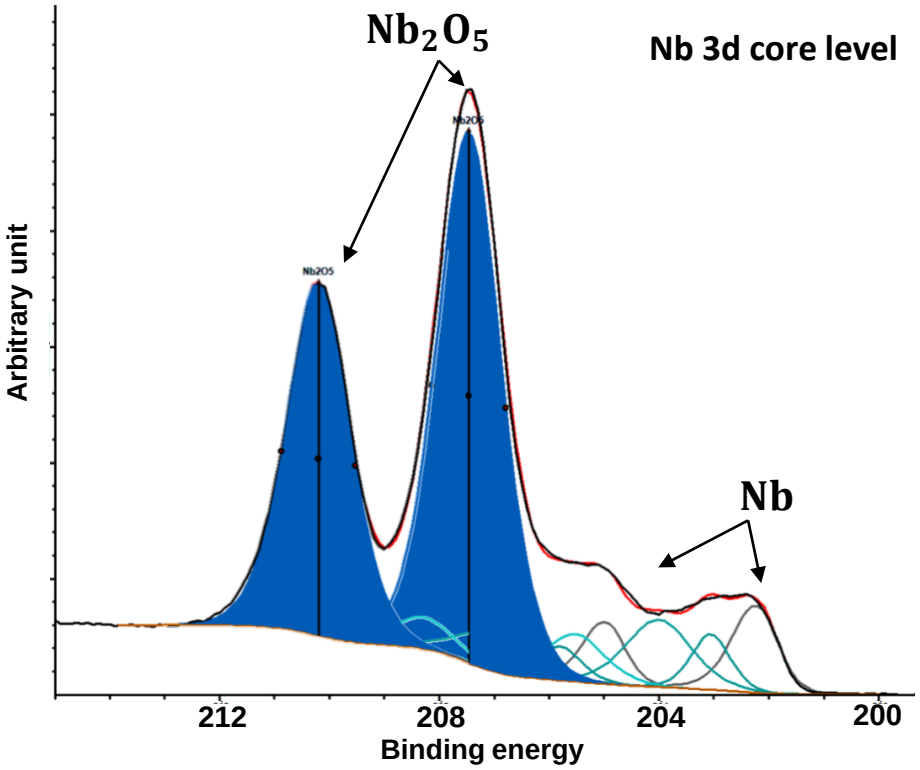

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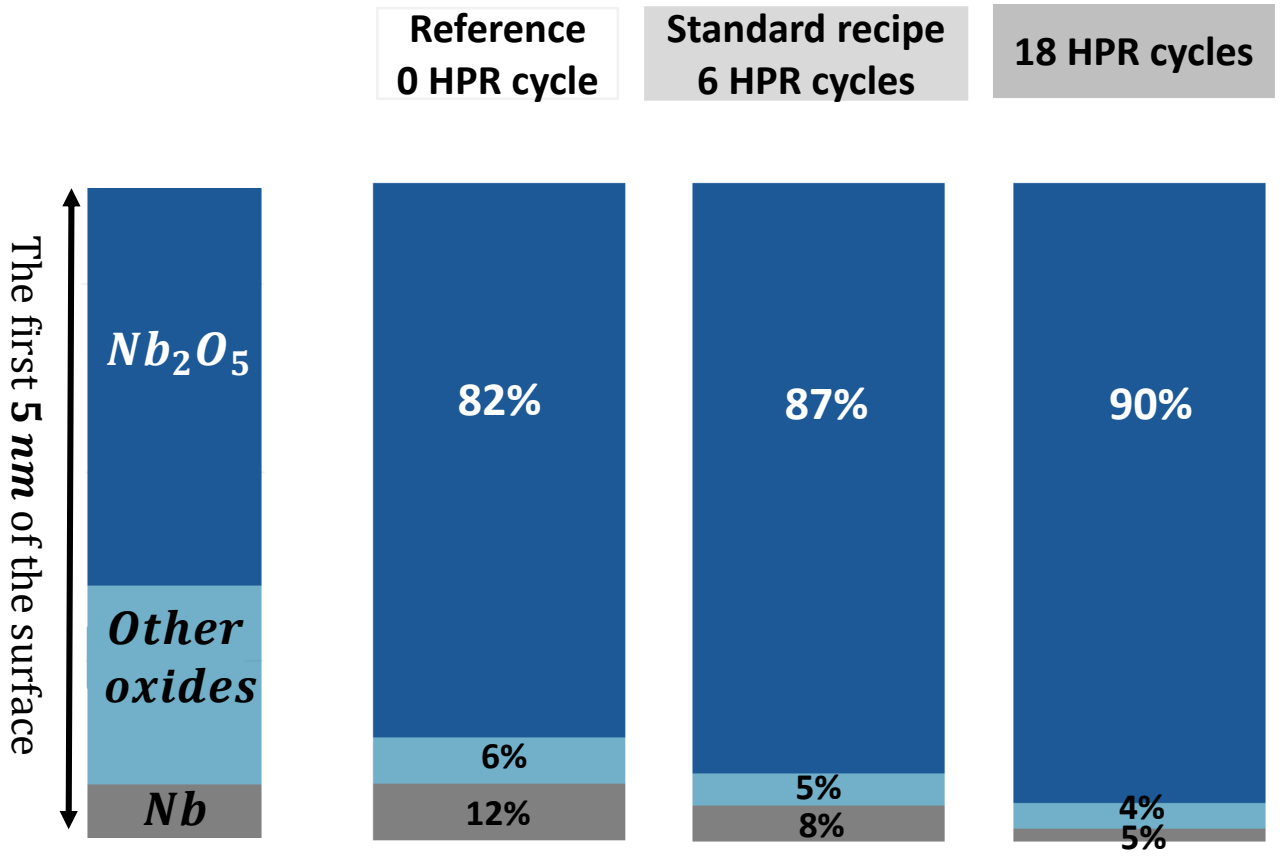
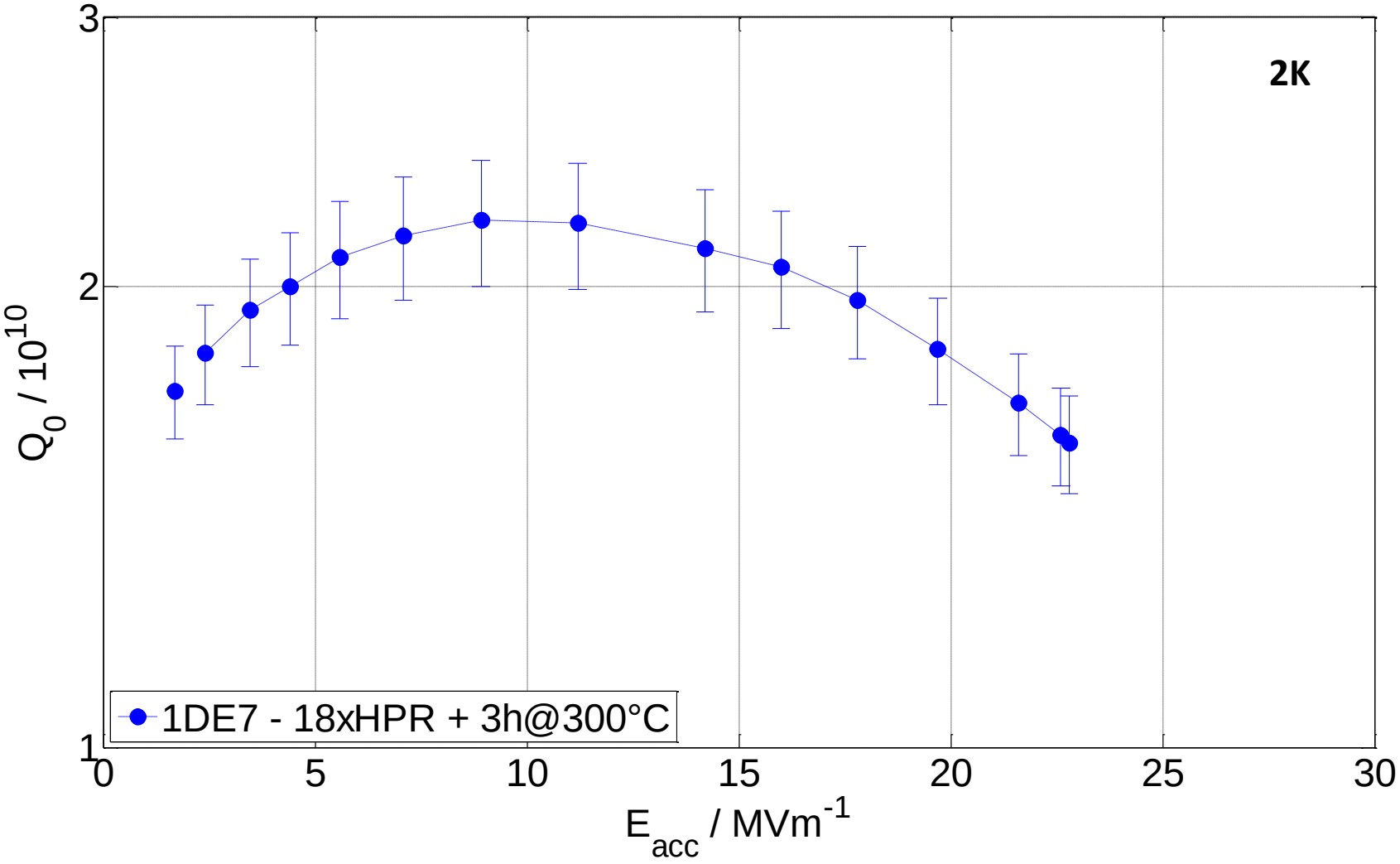


18x HPR is not beneficial for Q_0



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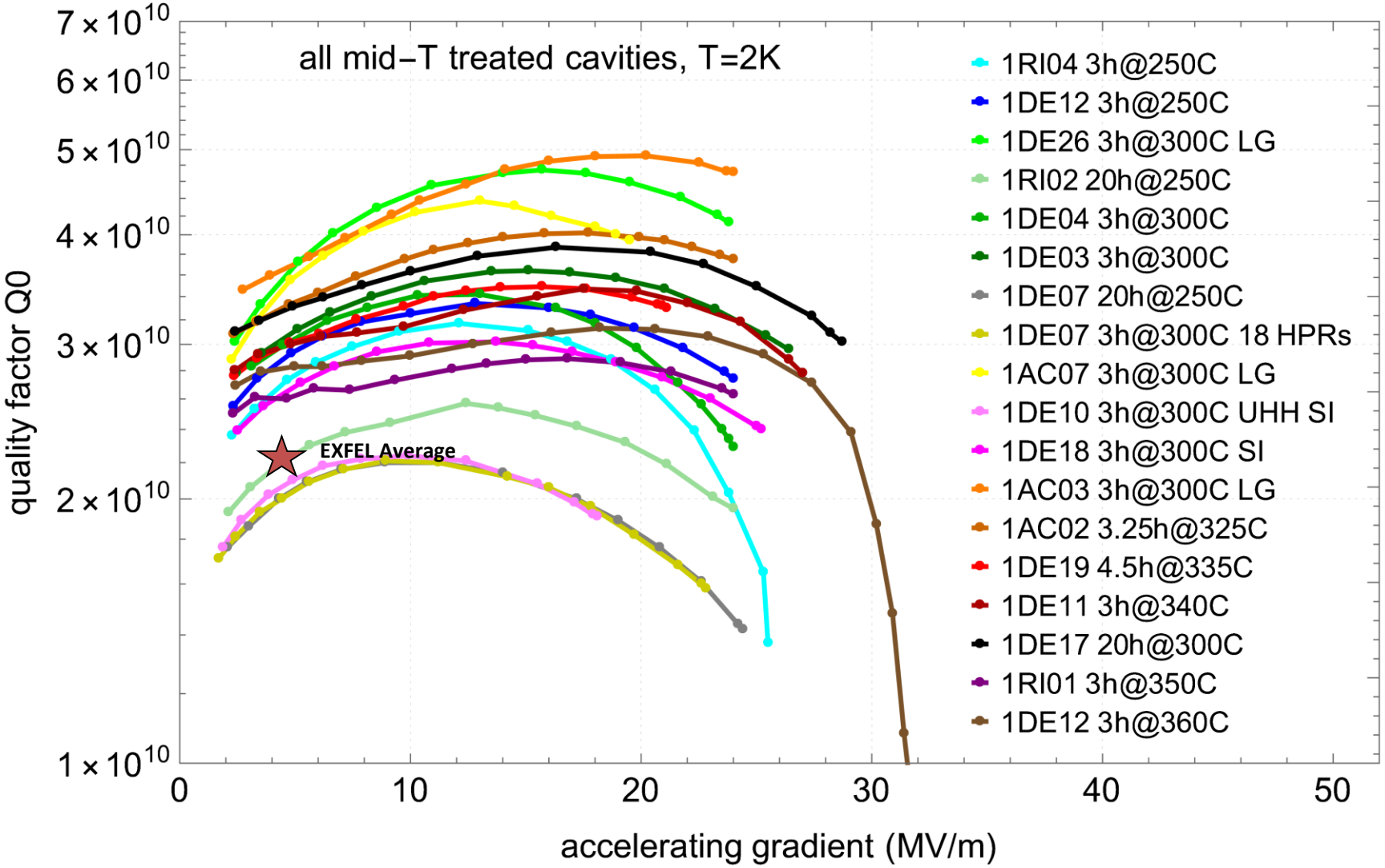

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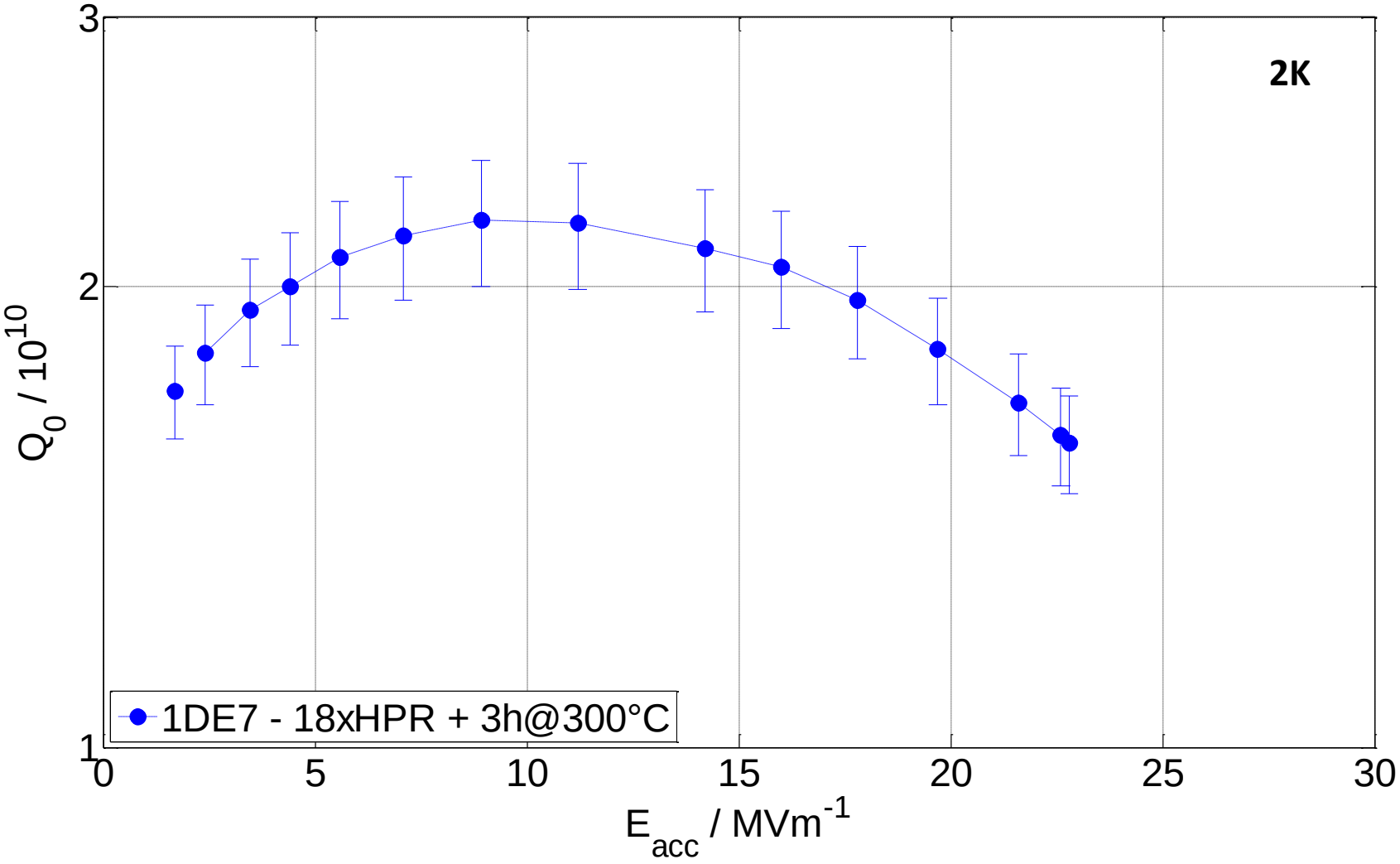
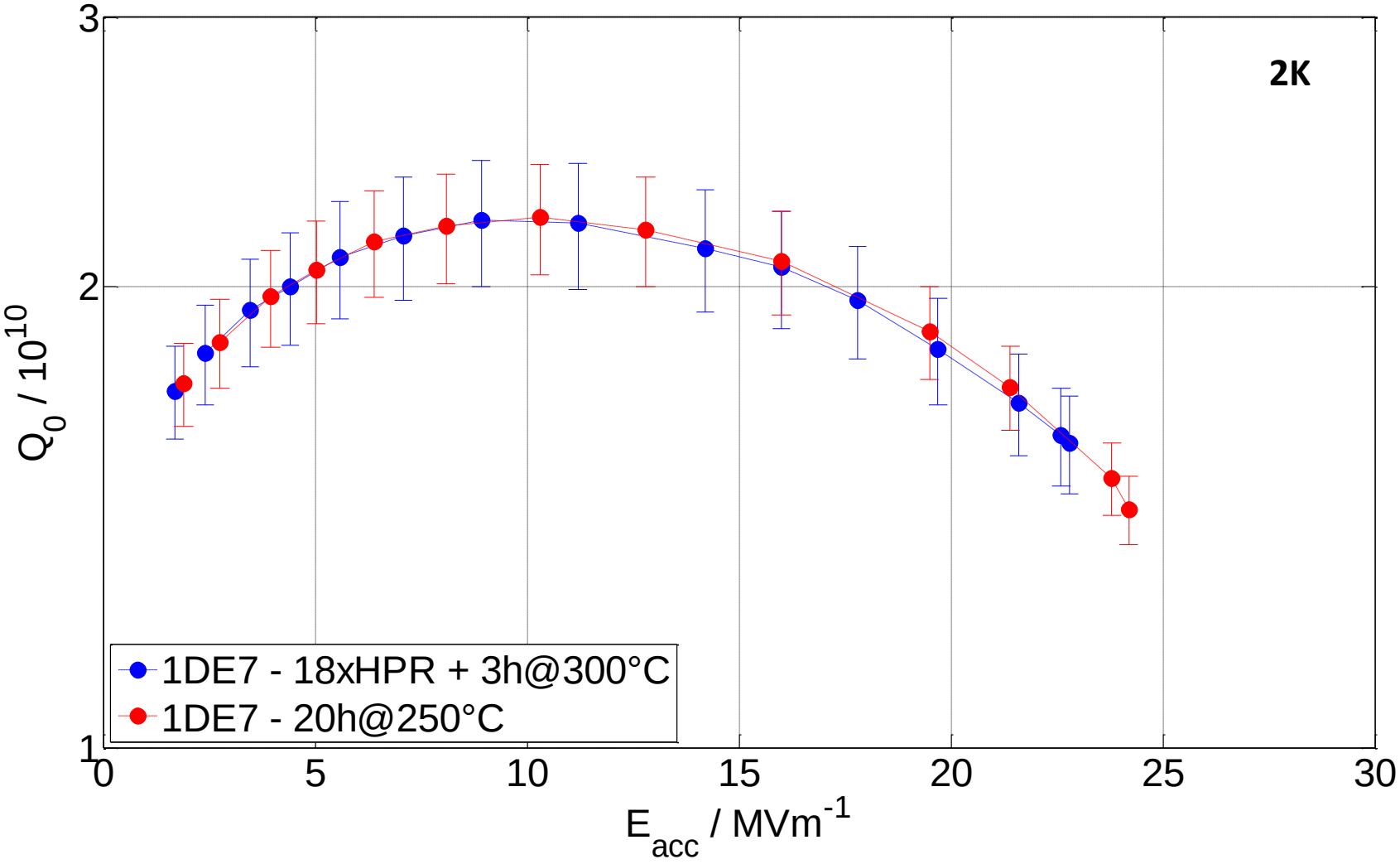
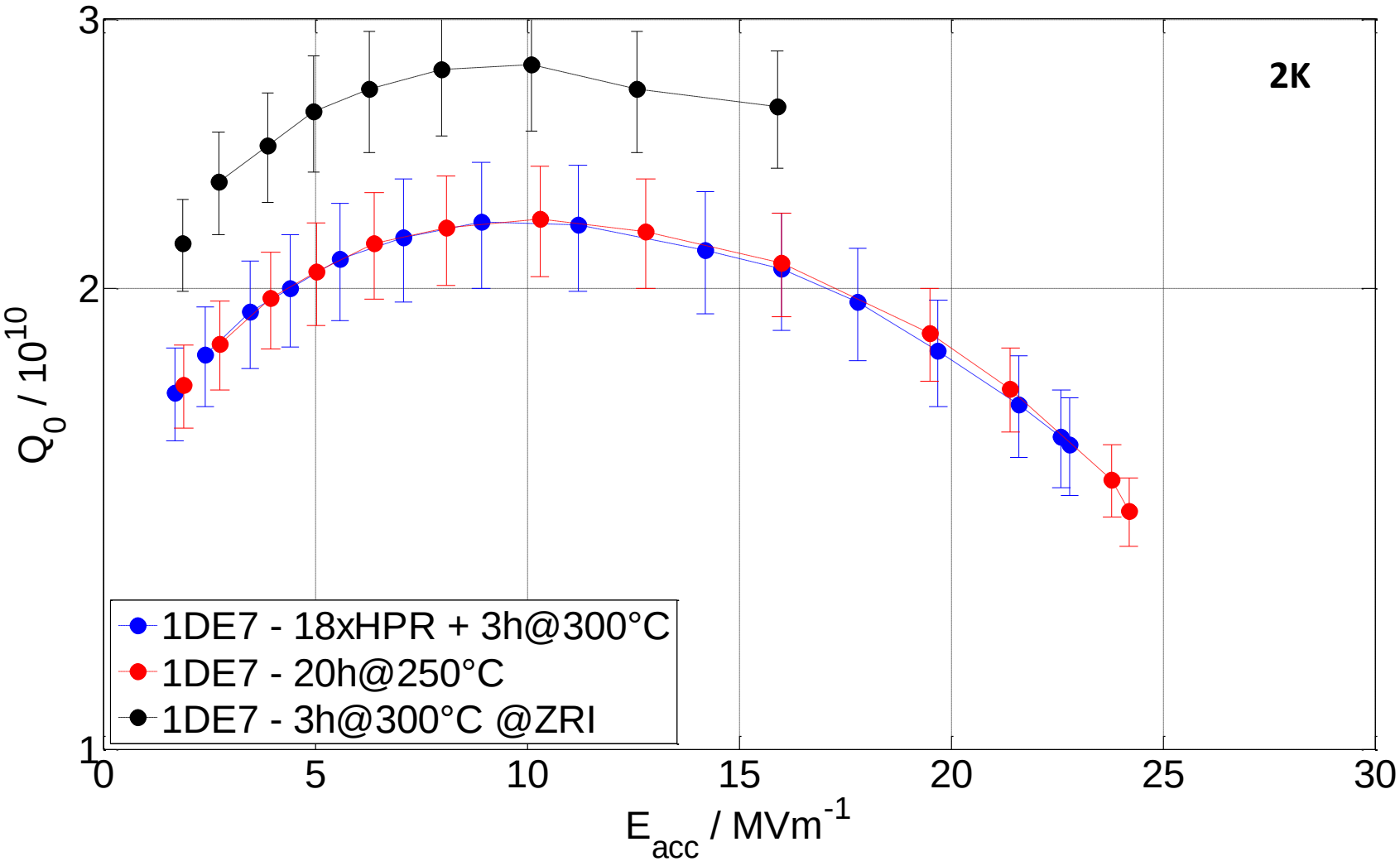


Different treatments – same rf behaviour



It‘s not the cavity!



20µm EP between black and red
40µm EP between red and blue

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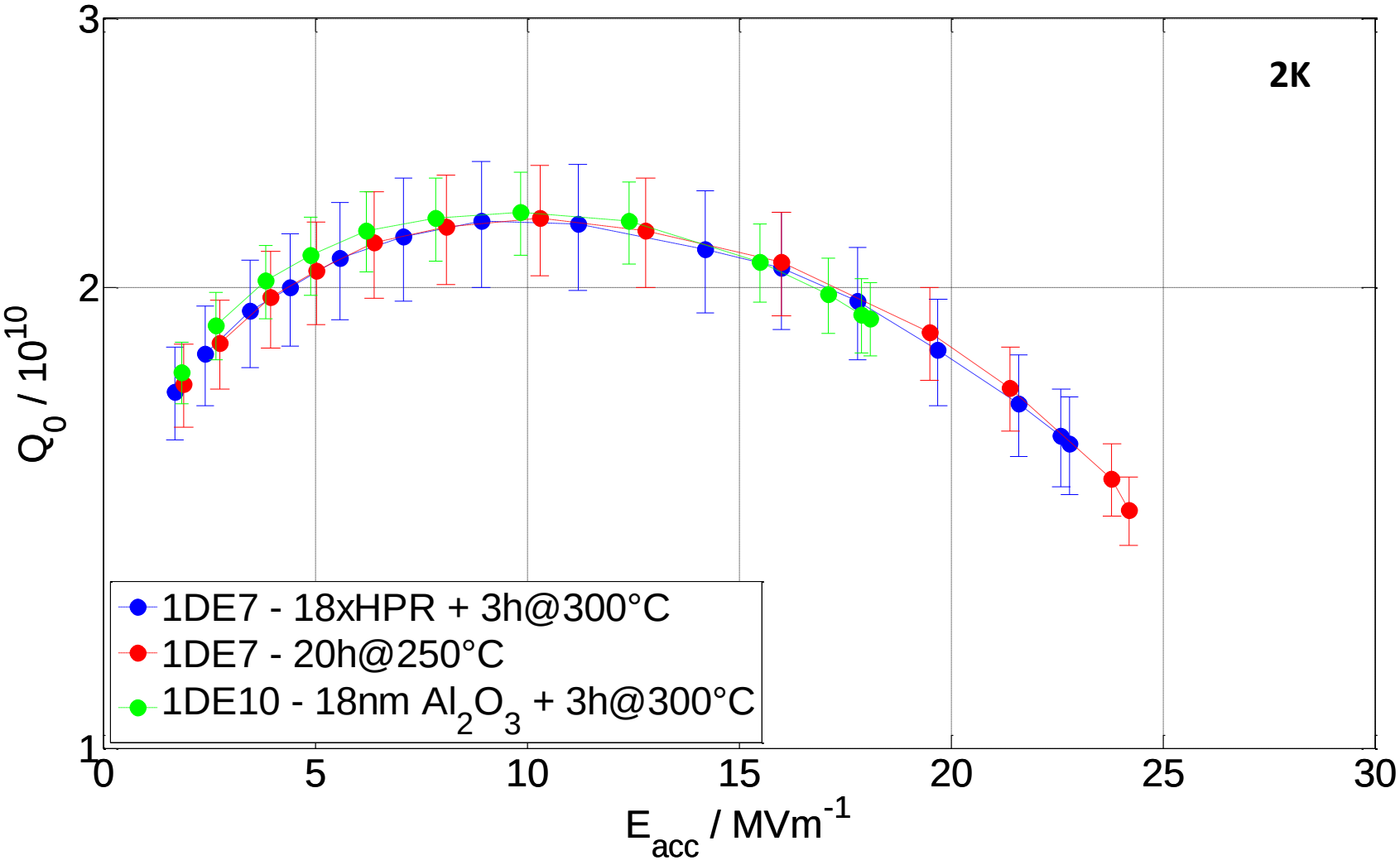

What information is encoded in f vs. T?

- Frequency shift is sensitive to interstitial concentration

$$\lambda(\ell, T) = \lambda_L(T)\sqrt{1 + \frac{\xi_0}{\ell}}$$ (equation valid for dirty limit)

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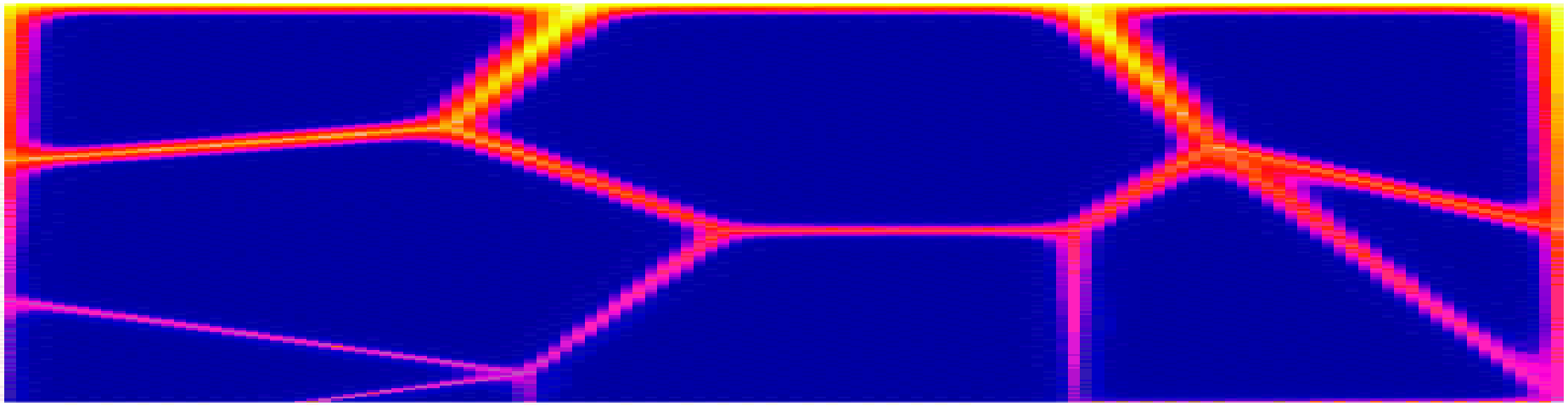

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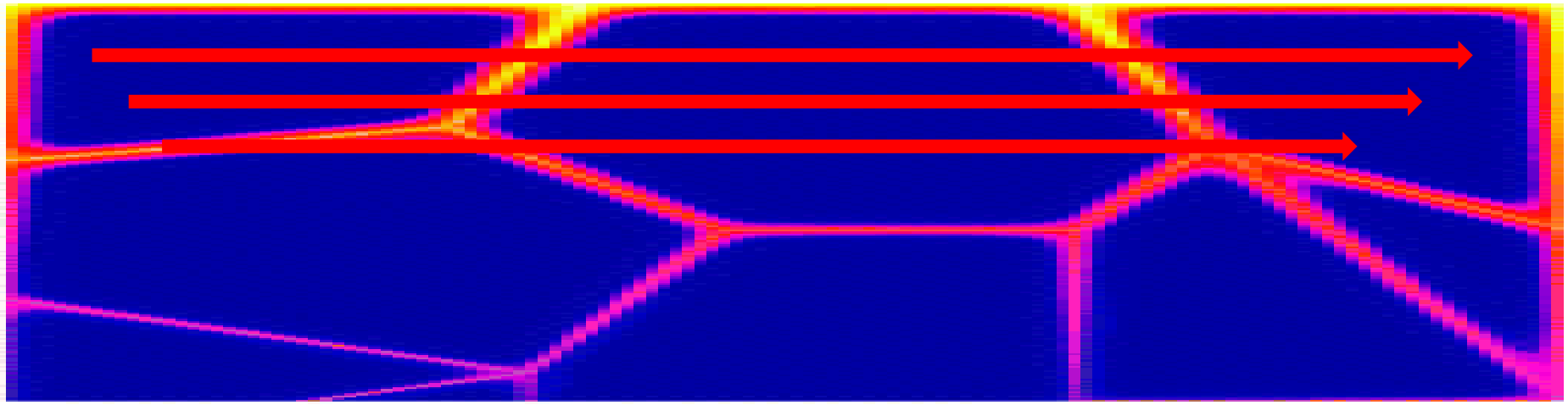
j



Skin depth

What information is encoded in f vs. T?

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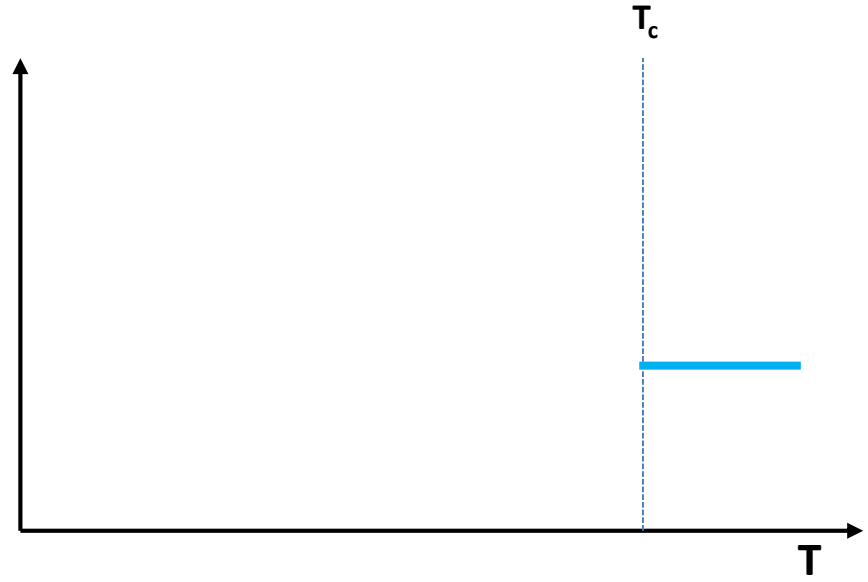

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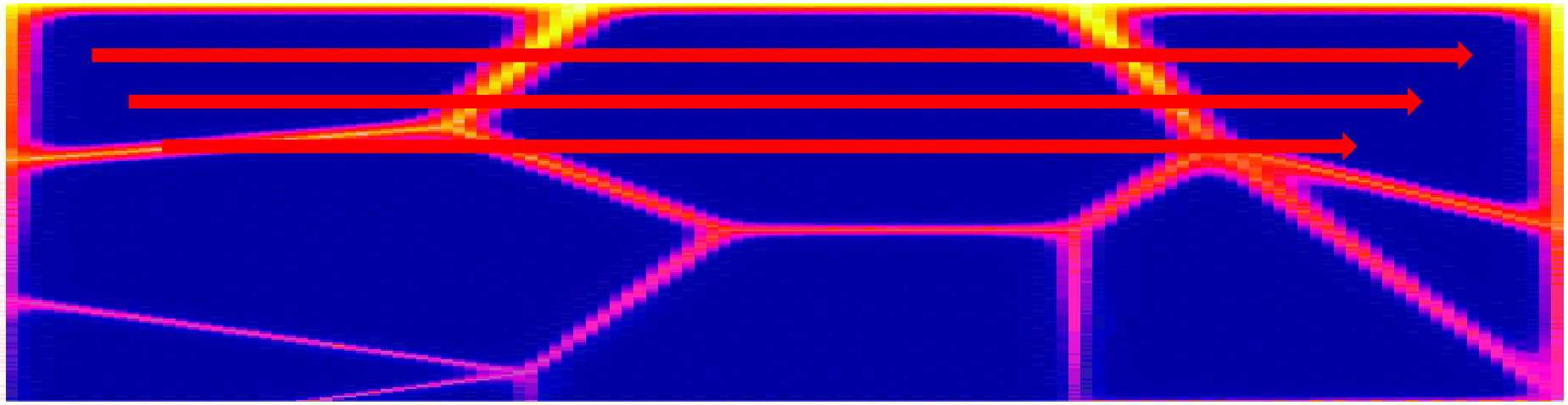

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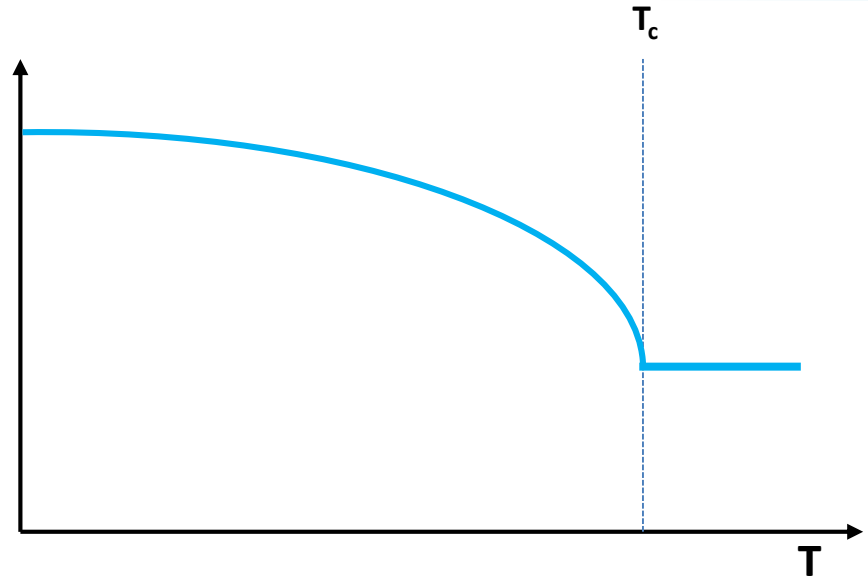

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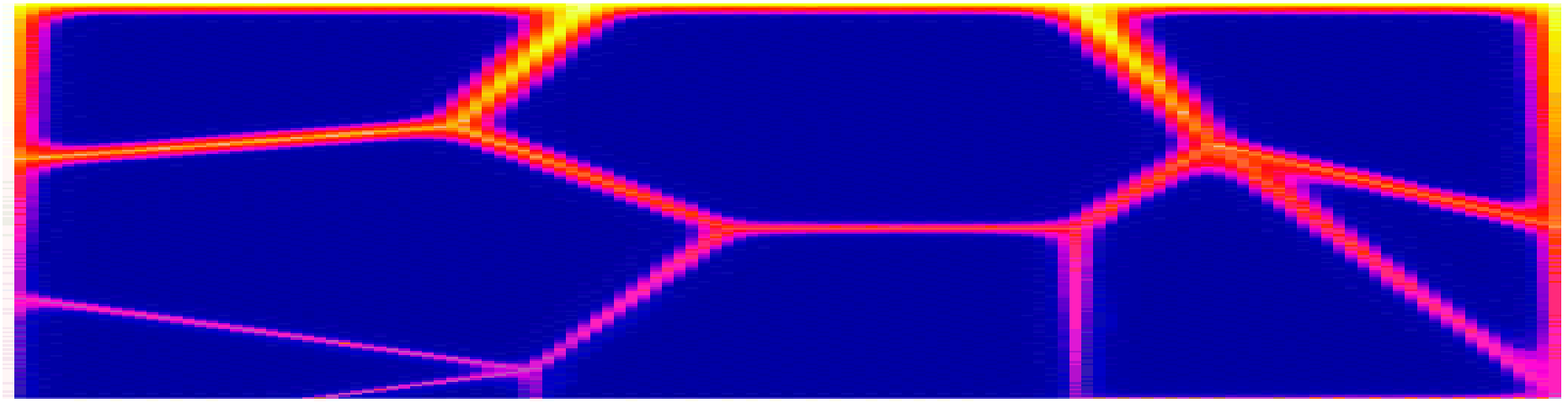

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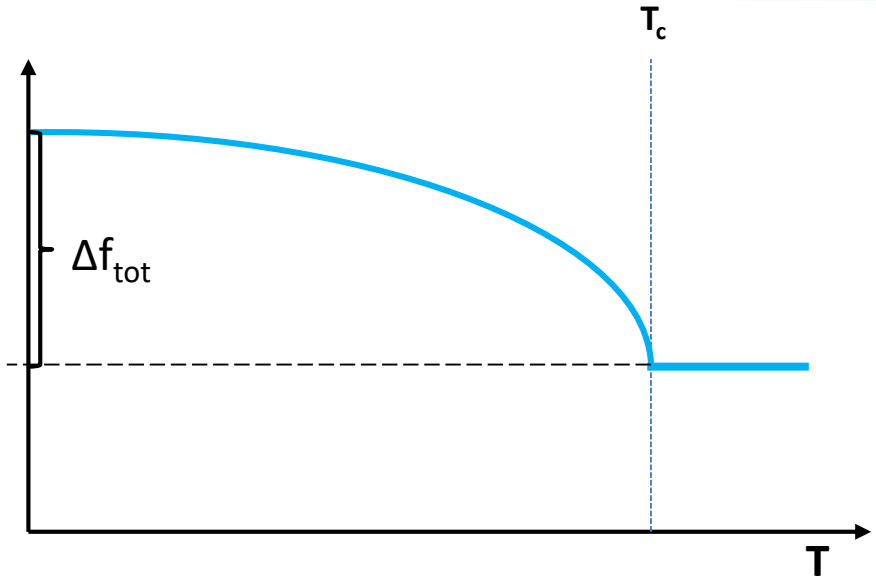

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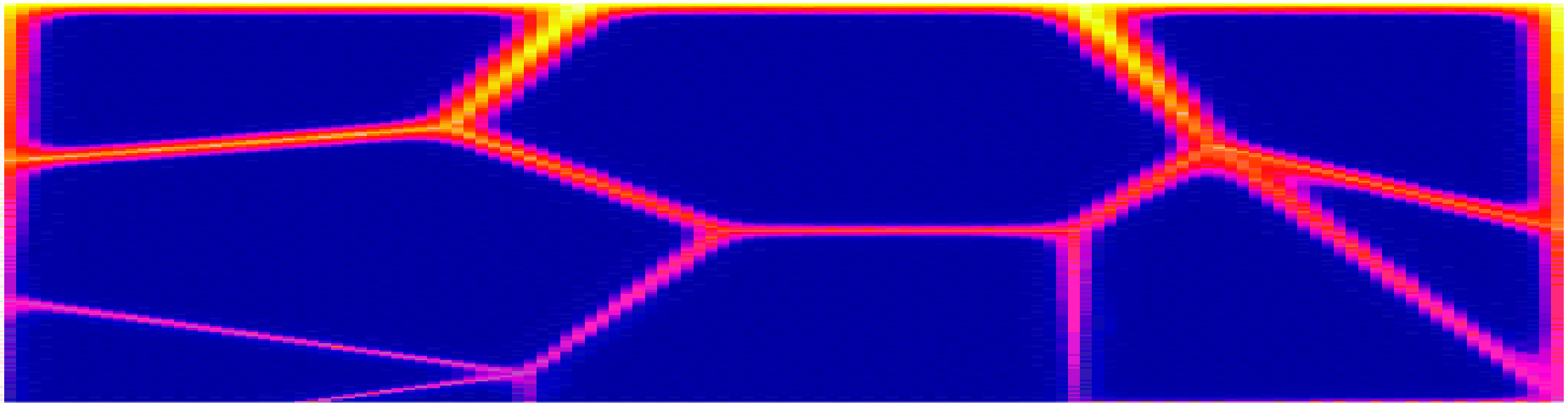
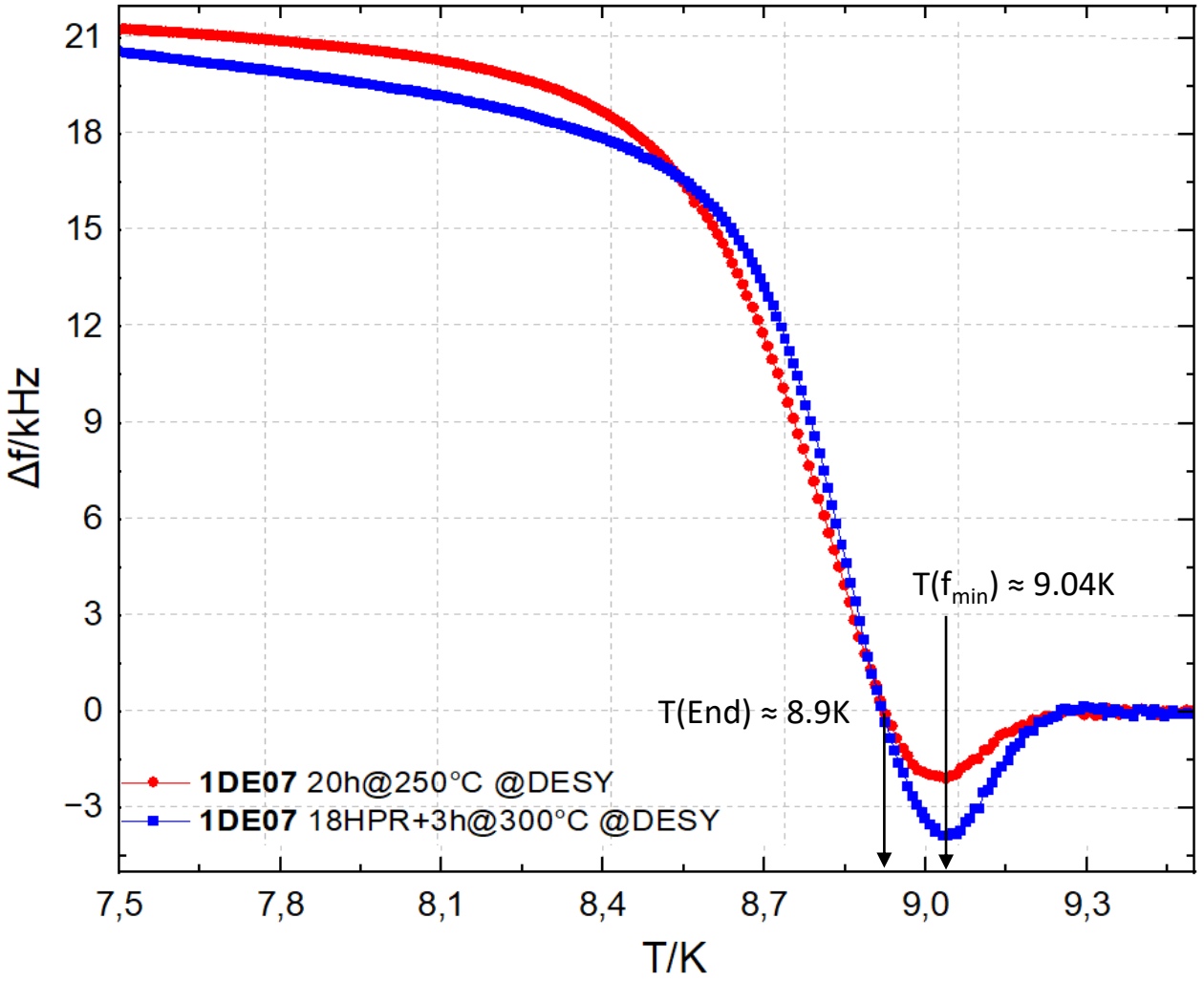
- Δf_{tot} for EXFEL type cavities is typcially 5-6 kHz

j



$\lambda(\ell, T)$

Dip is deeper for 18xHPR – Δf_{tot} similar



- Mid-T: more interstitials → larger Δf, but yet no dip

Cavity	Treatment	Δf_{dip}/kHz
1DE19	4.5h @ 335°C	1.1
1AC02	3.25h @ 335°C	1.4
1RI04	3h @ 250°C	0.9
1DE07	20h @ 250°C	2.0
1DE79	18xHPR + 3h @ 300°C	3.9

Microscopic model for disordered superconductor

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[Desorbo, W. *Phys. Rev.* 132 (1963): 107.]

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→ Only locally saturated – not globally. If SIMS spot size ≈ multiple grains, obtained c_O below saturation limit

Local Disorder: SIMS is too coarse

- Local disorder ≈ order of grain size and less (50 µm)
- SIMS spot size is usually ≈ 100x100 µm² or larger

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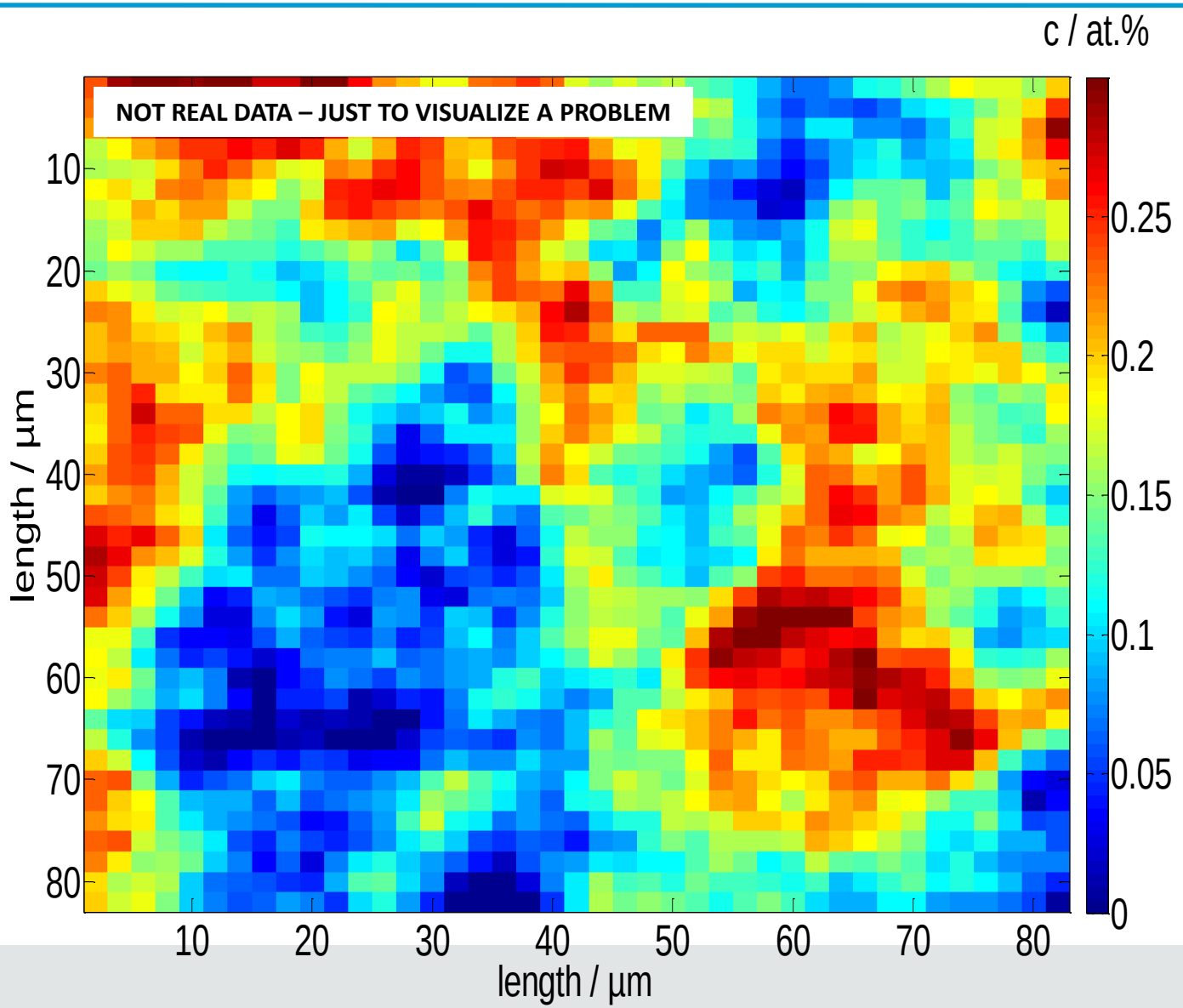

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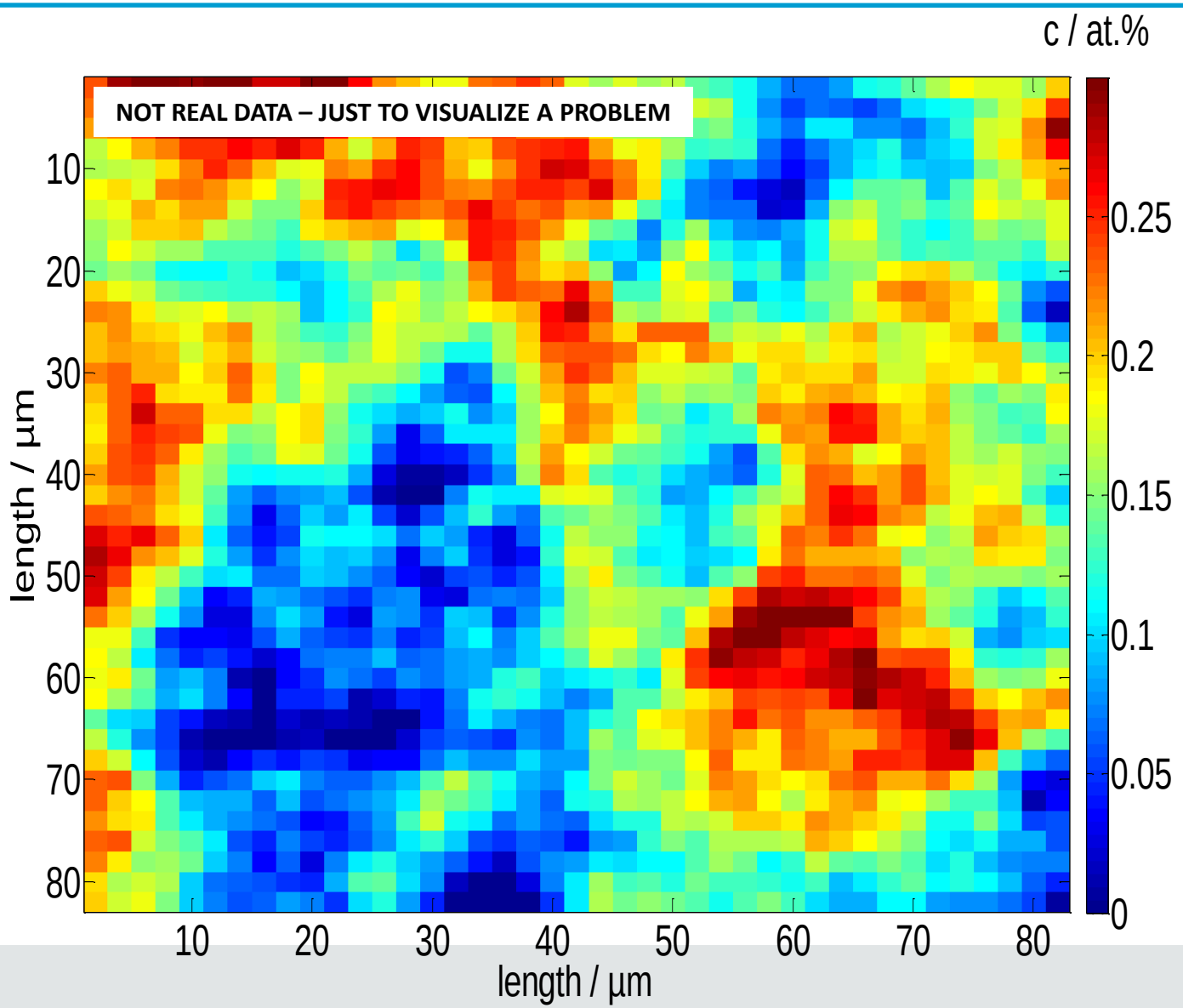

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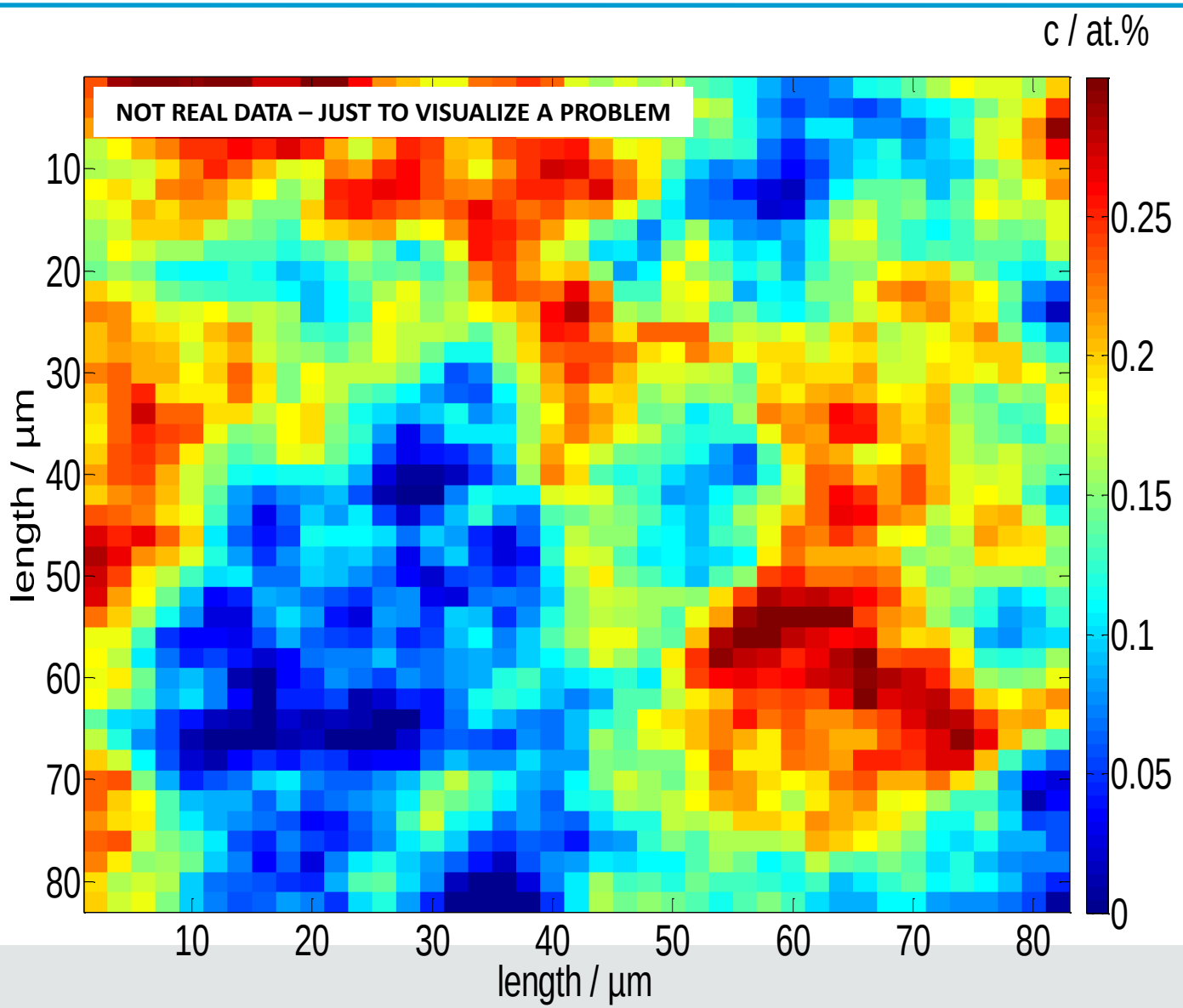

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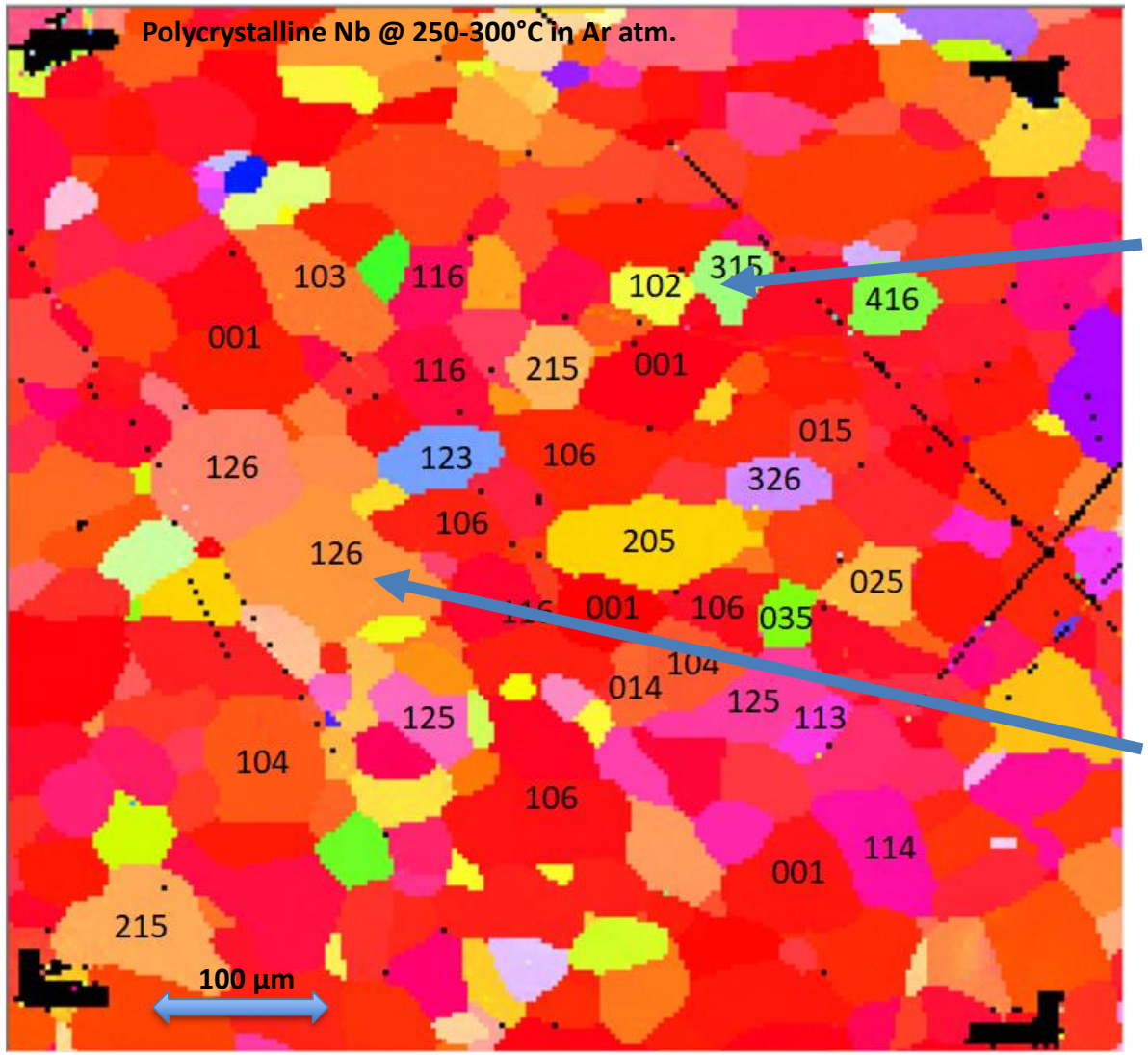
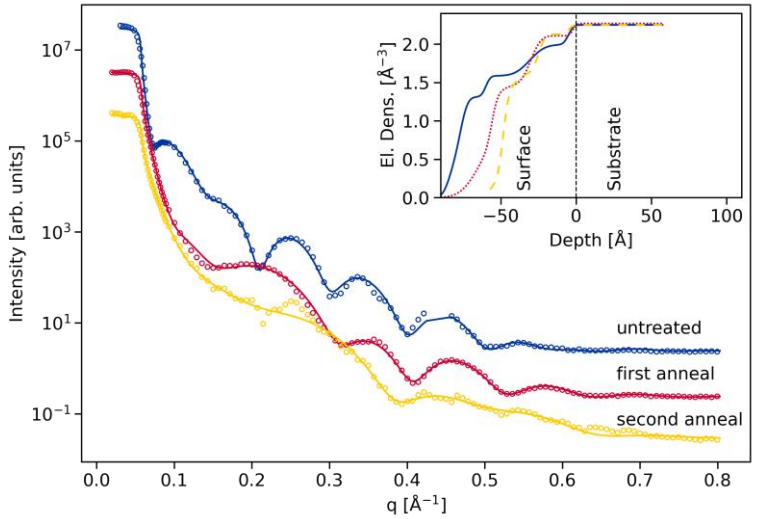
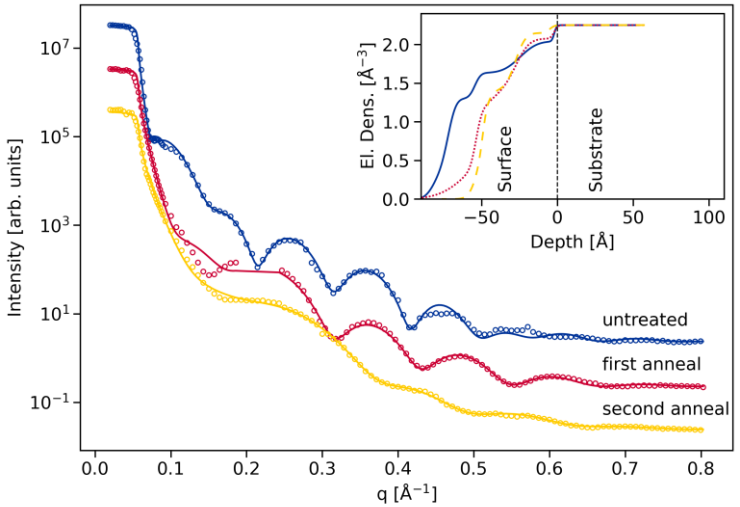
- Need for better spatial and chemical resolution

  → „Grain Mapping“

Grain observation under heat treatment with XRR





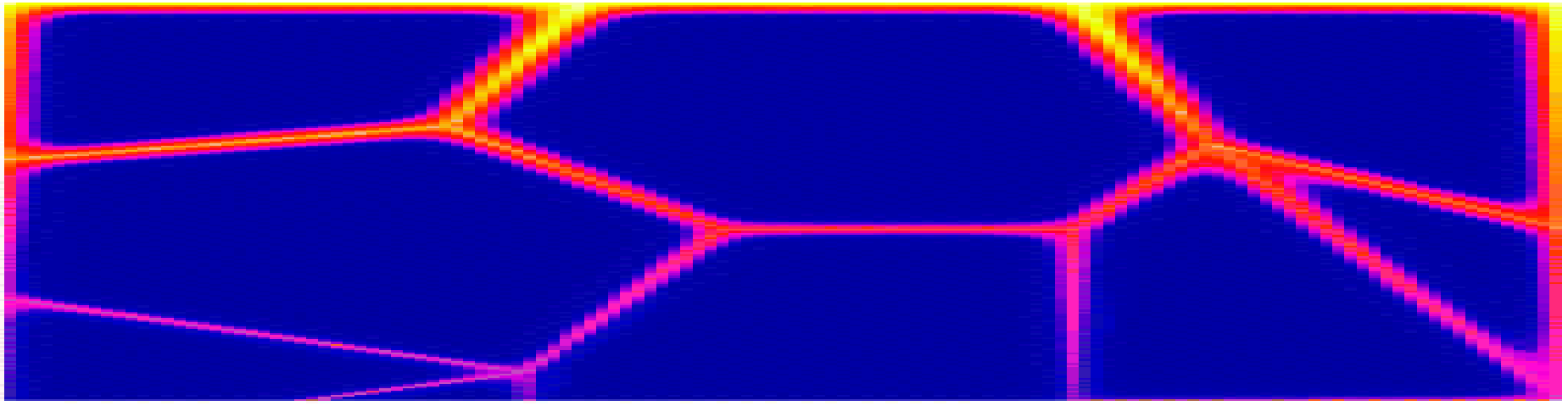


To be published

Disordered superconductor show dip

[Barra, M., et al. *SUST* 18.3 (2005): 271.]

$$f_{tot} \propto \frac{\Gamma}{\lambda(\ell, T)}$$



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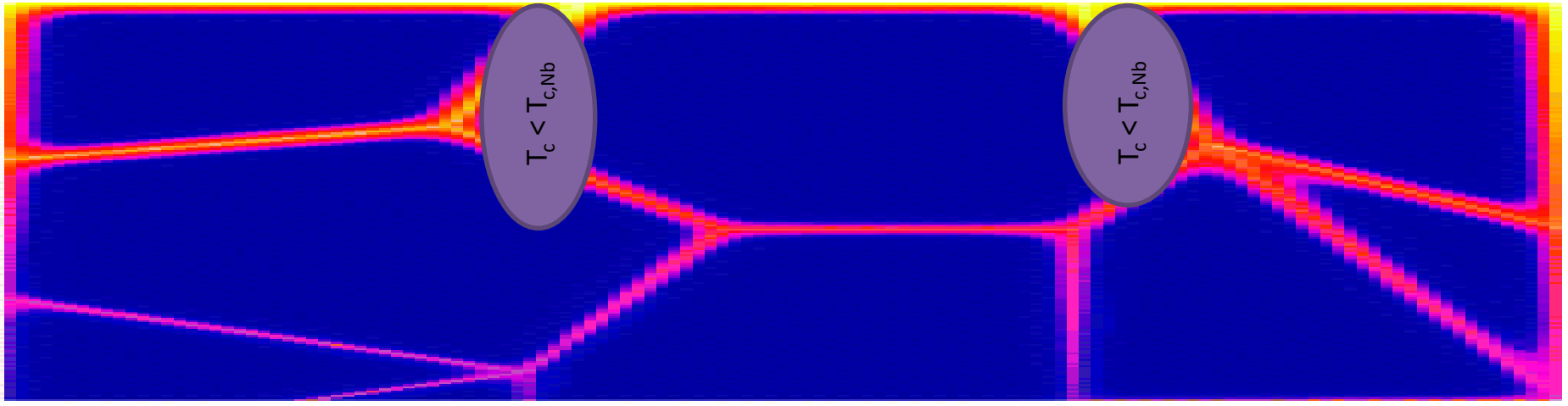

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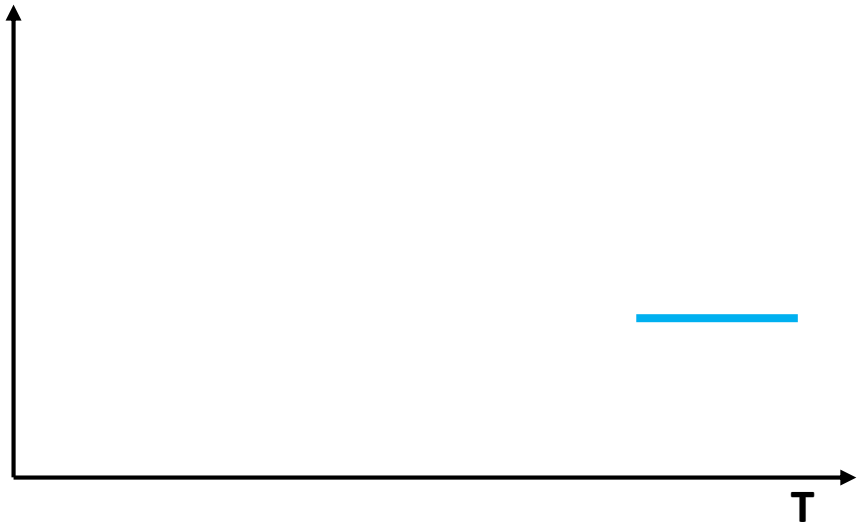

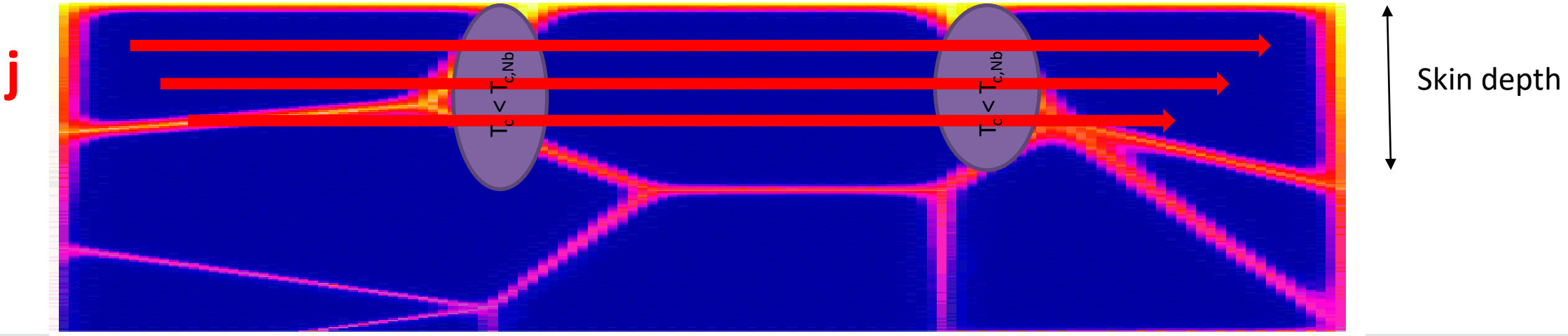

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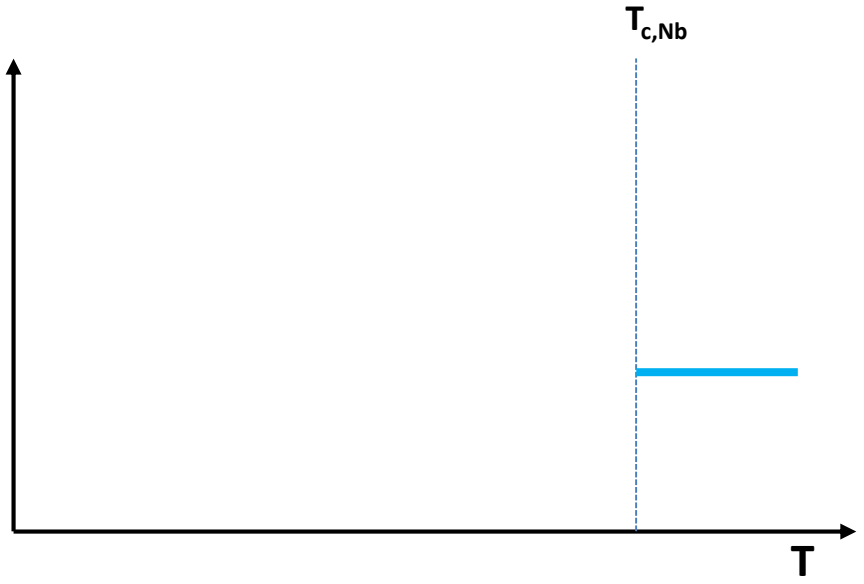

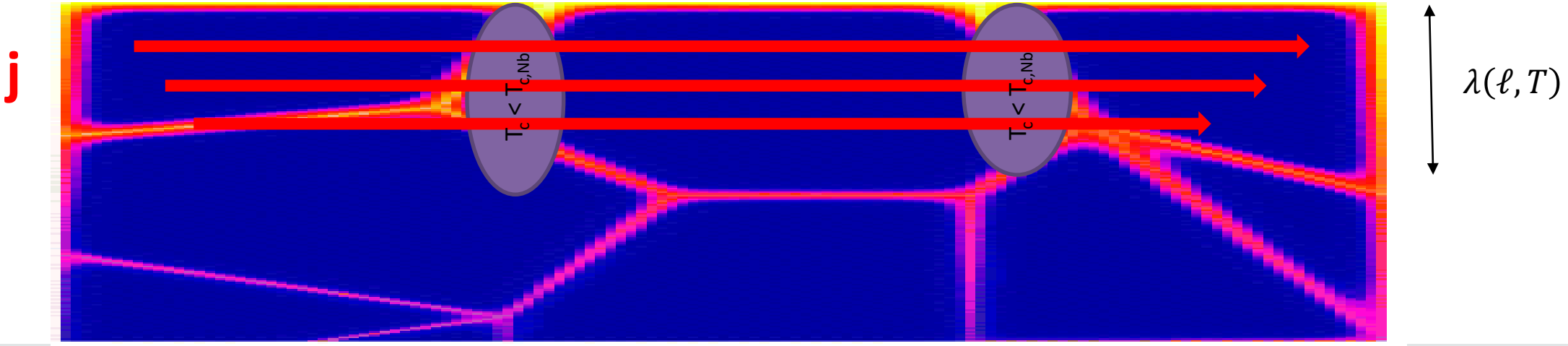

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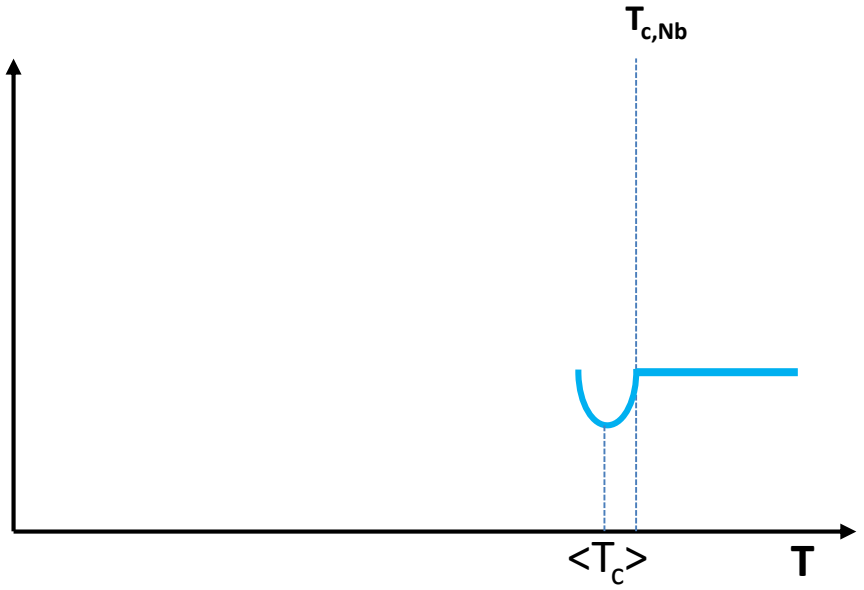

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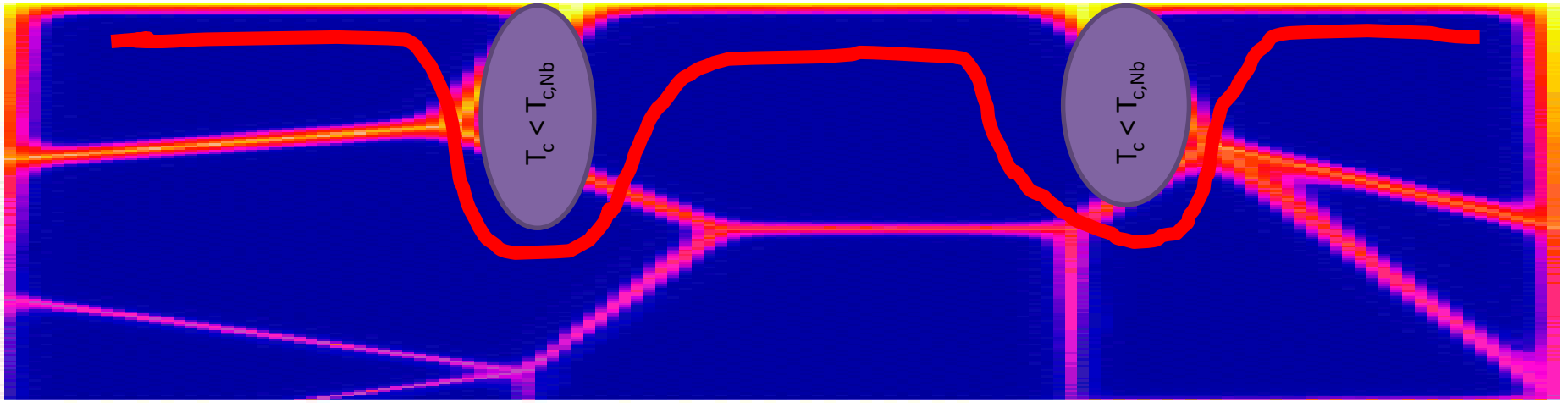

$\lambda(\ell, T)$

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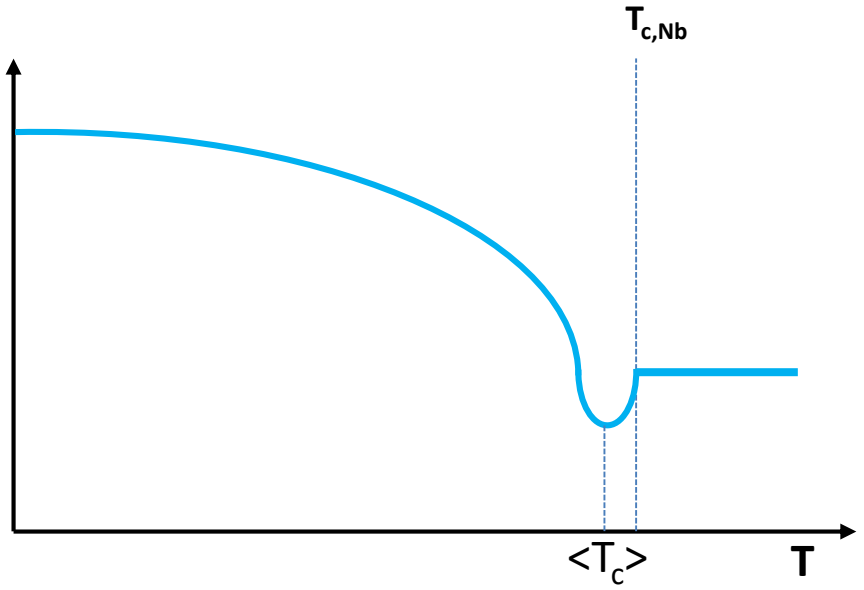

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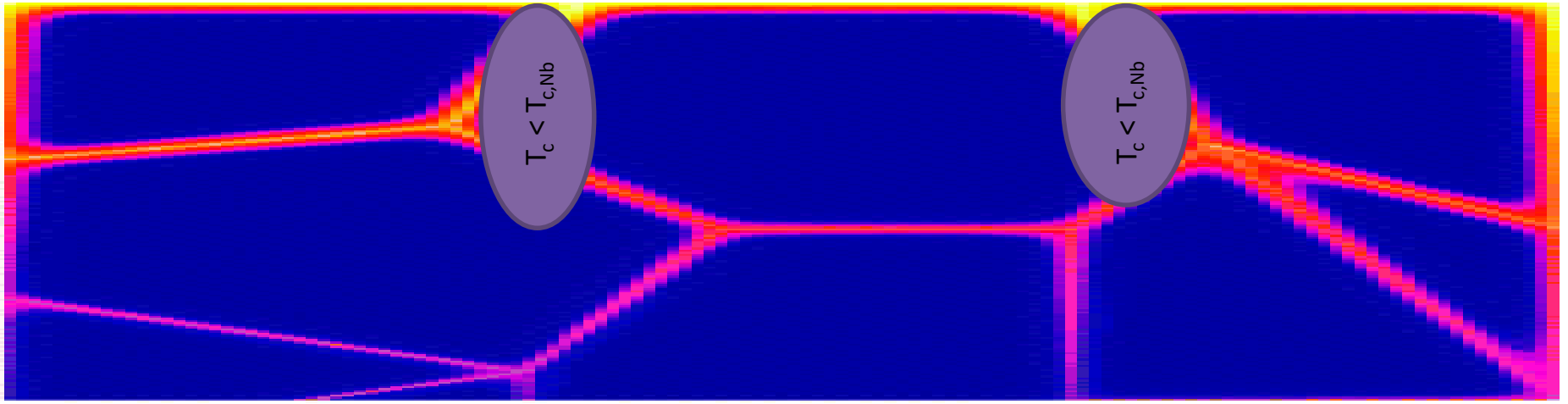

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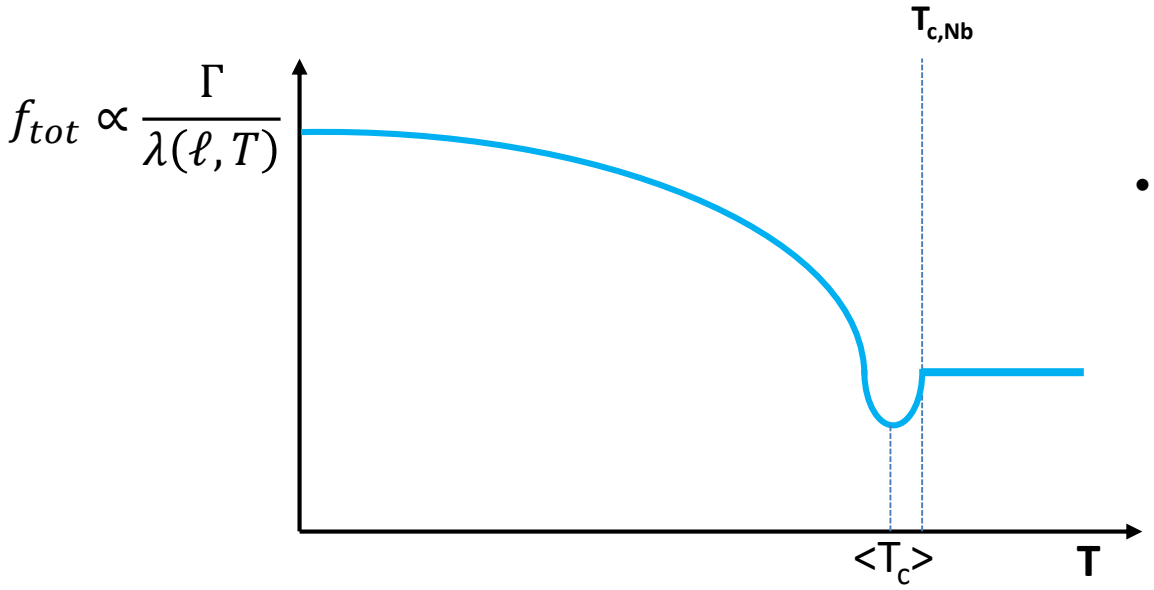

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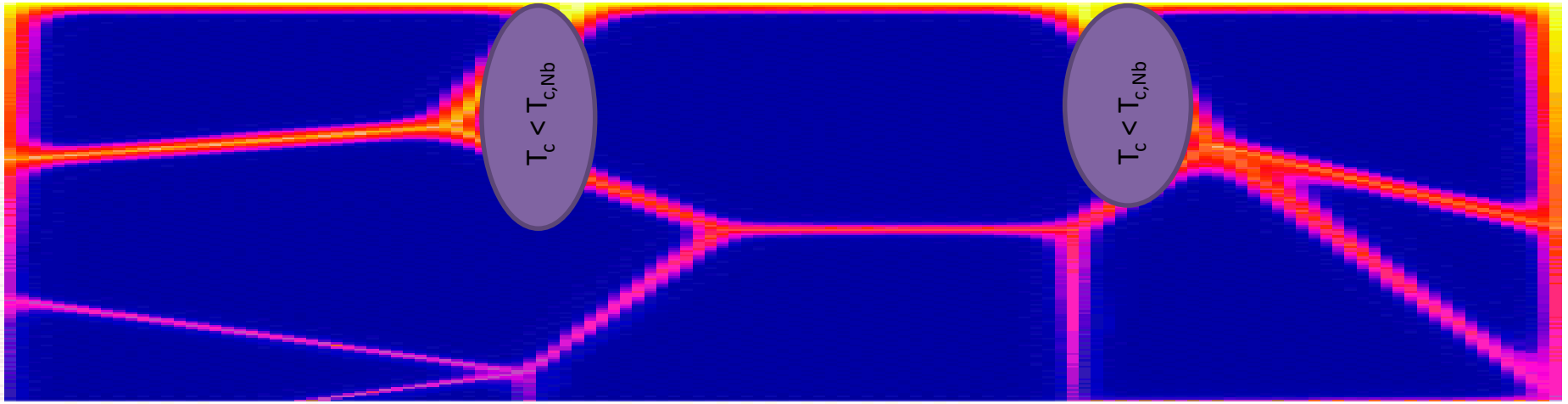

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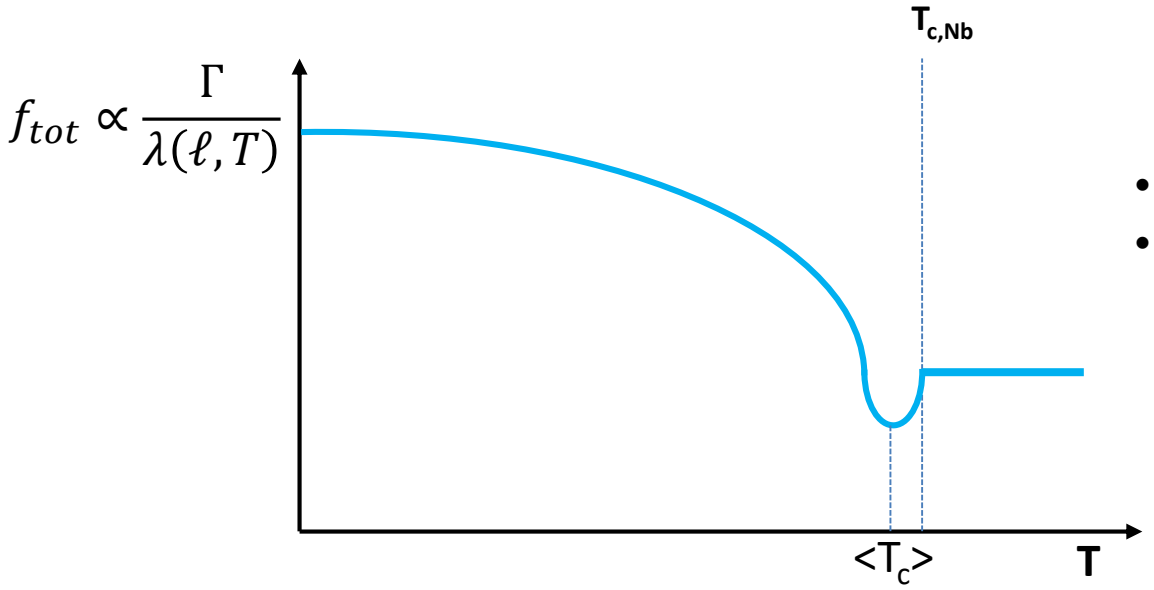

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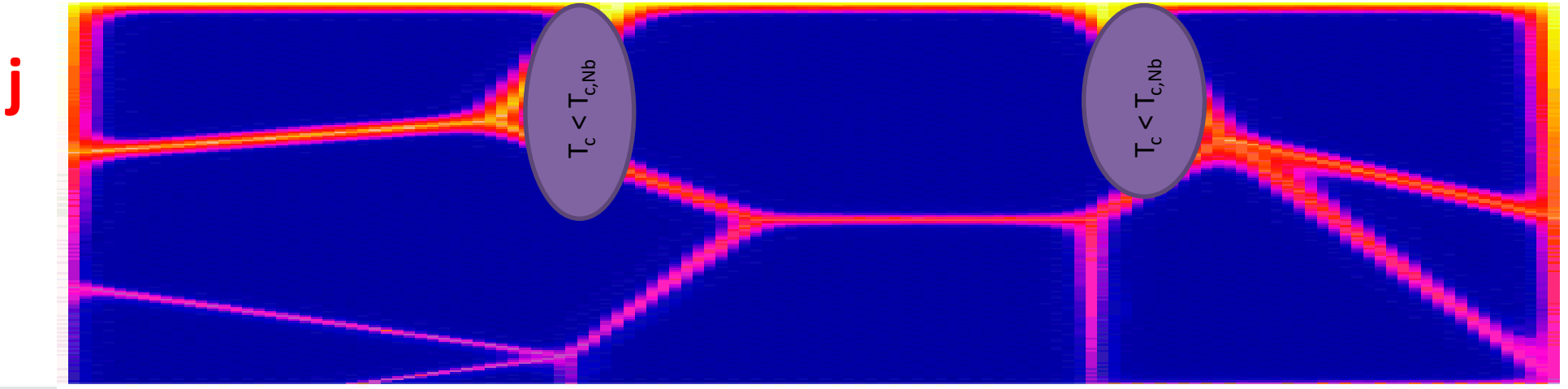

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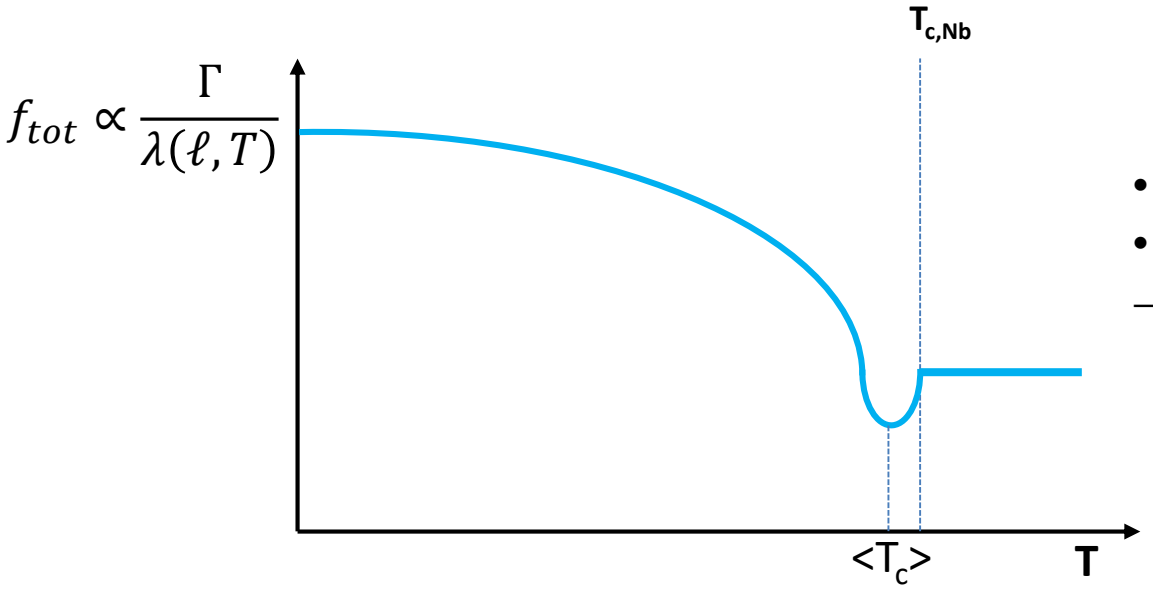

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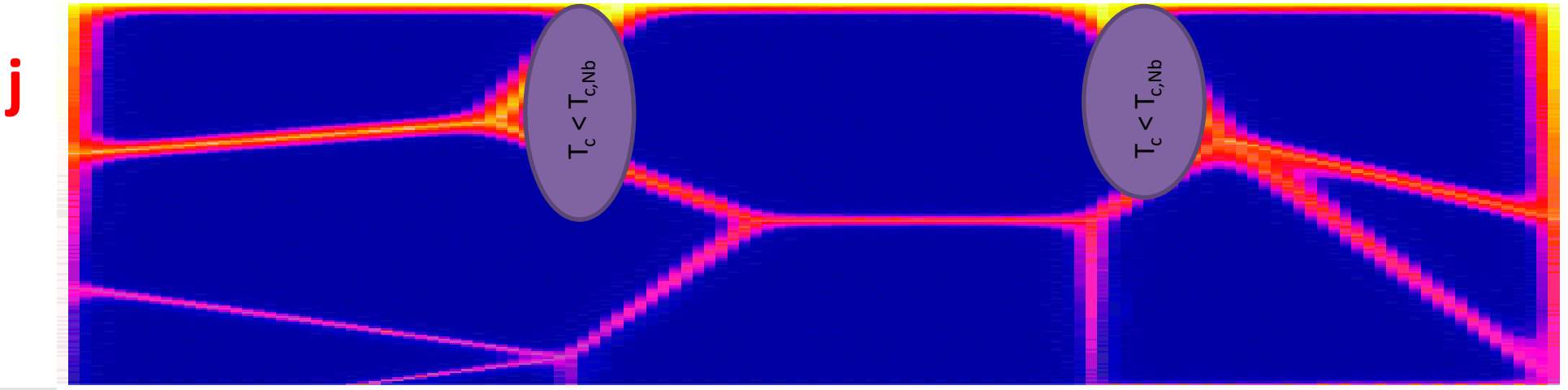
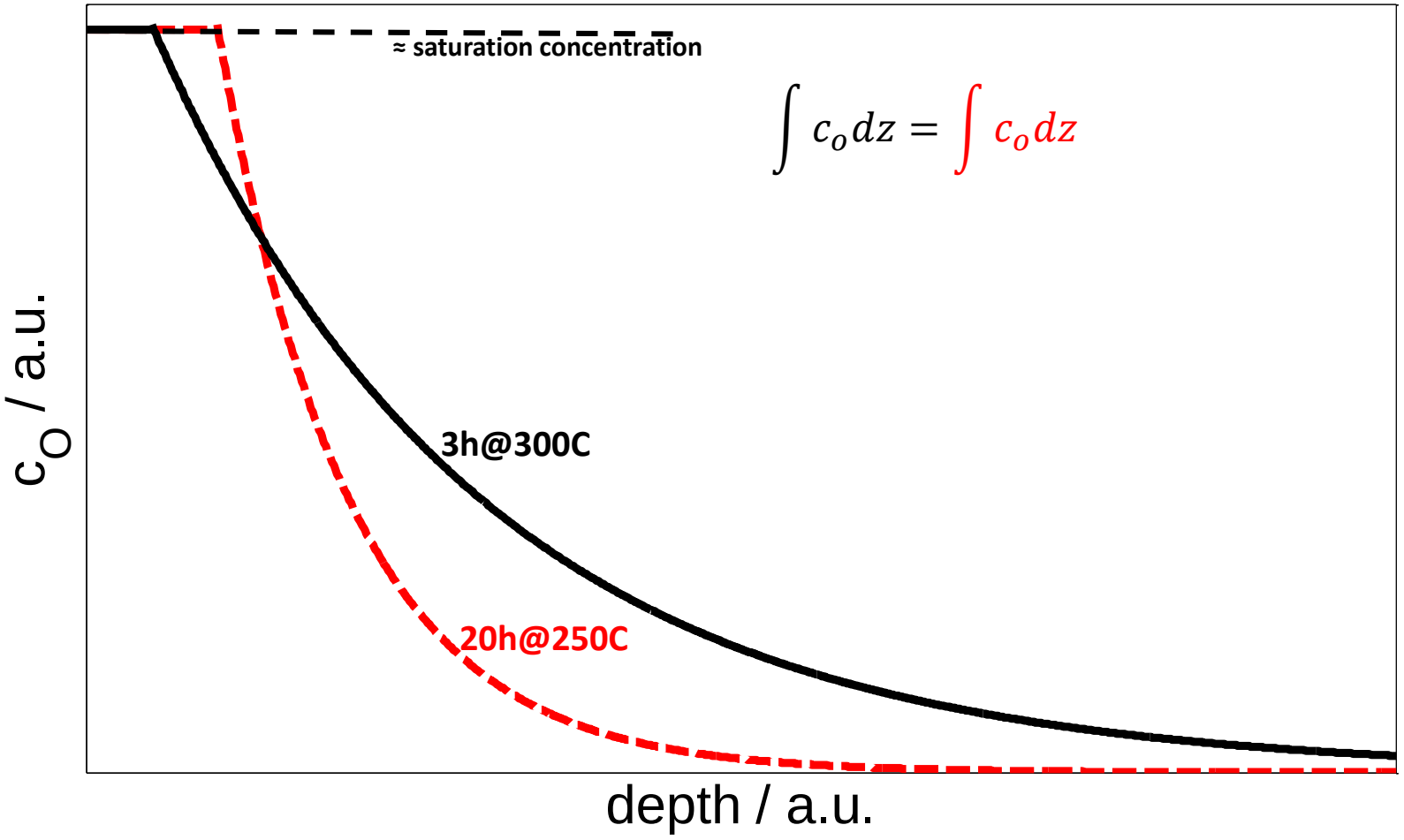
→ Dip caused by clusters and not homogenous O-enriched Nb-layer



$\lambda(\ell, T)$

If it acts the same – is it the same?



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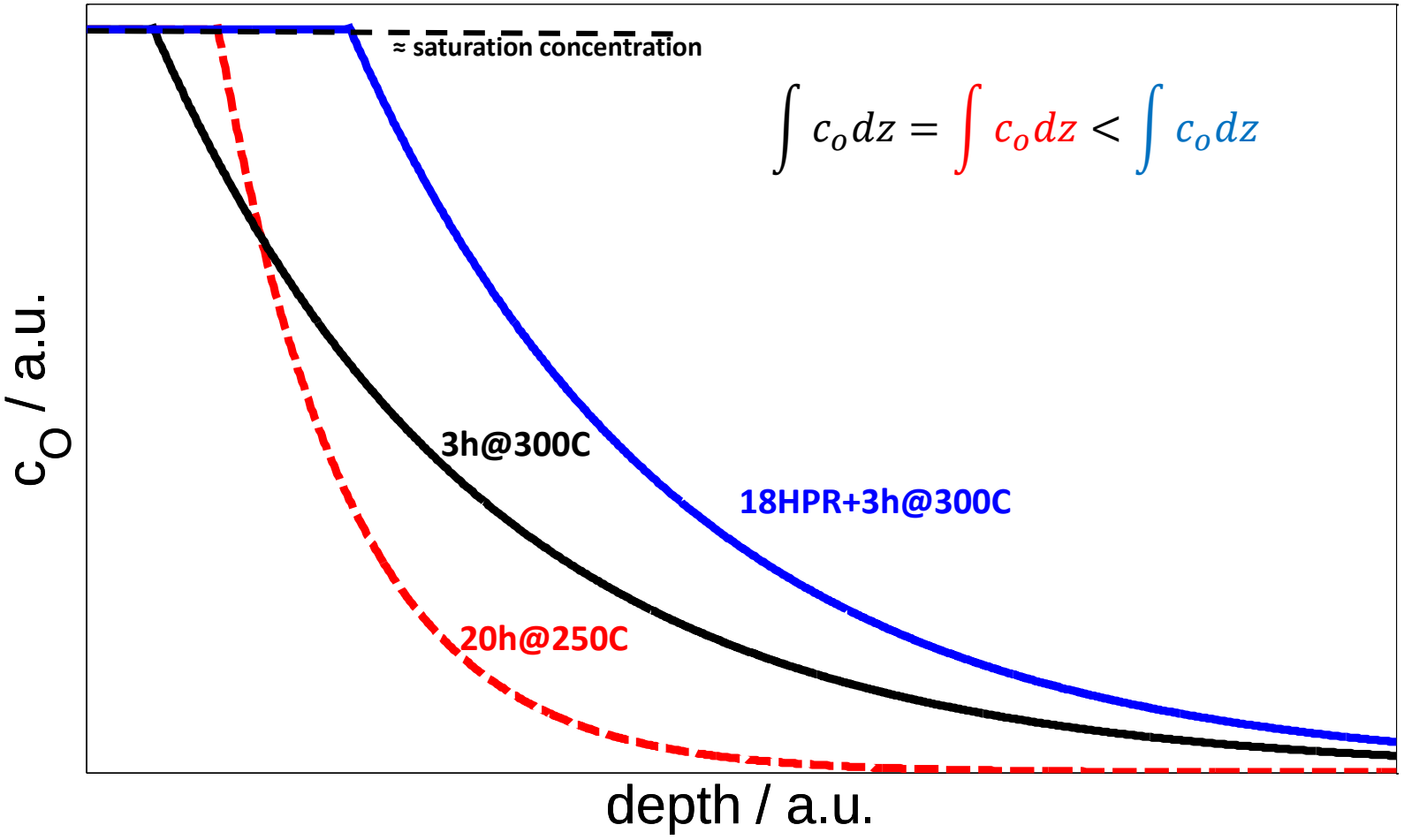

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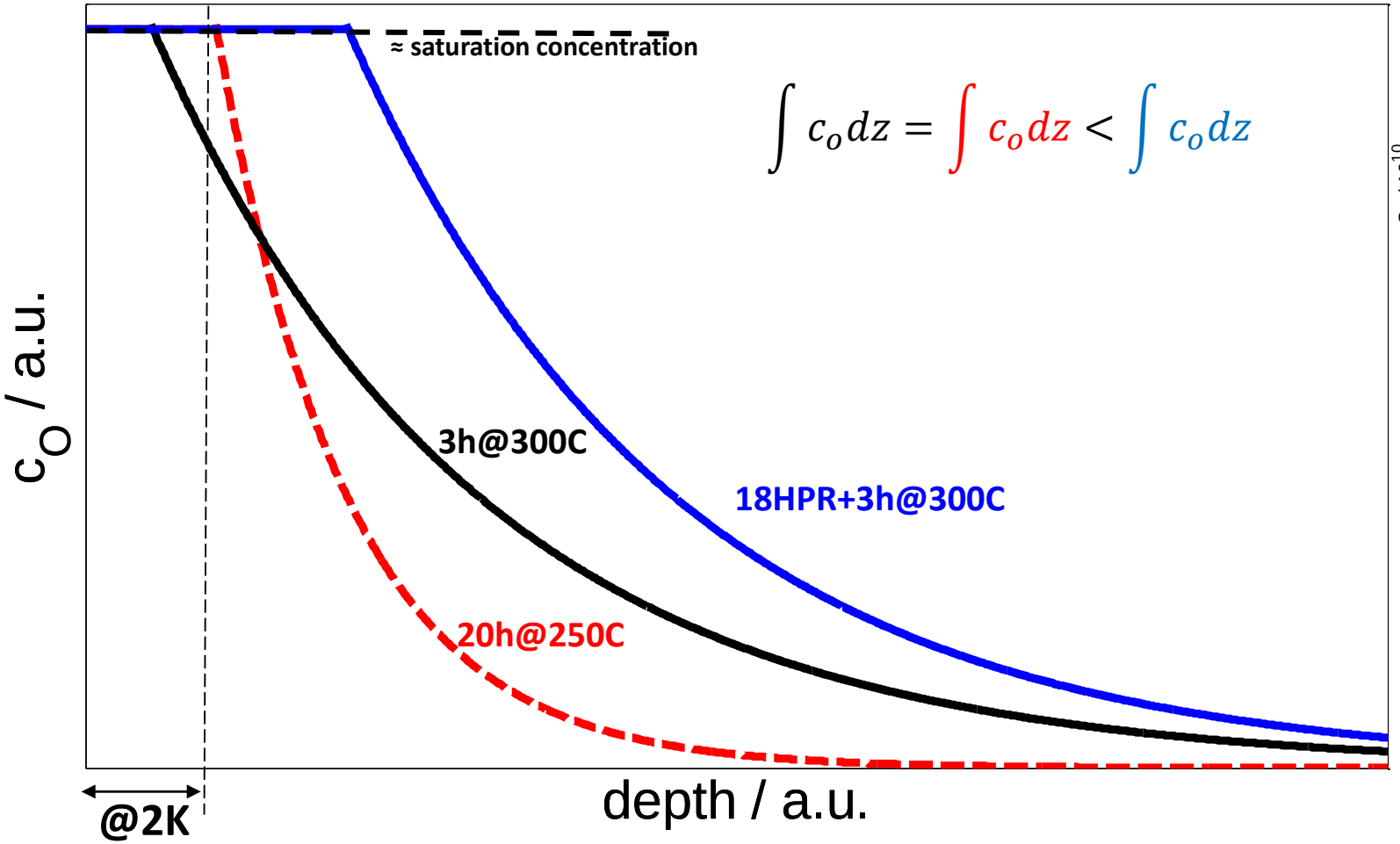

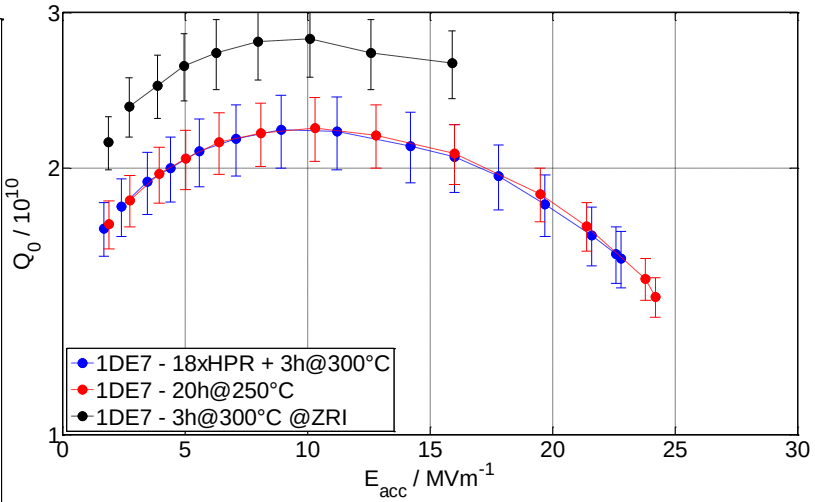

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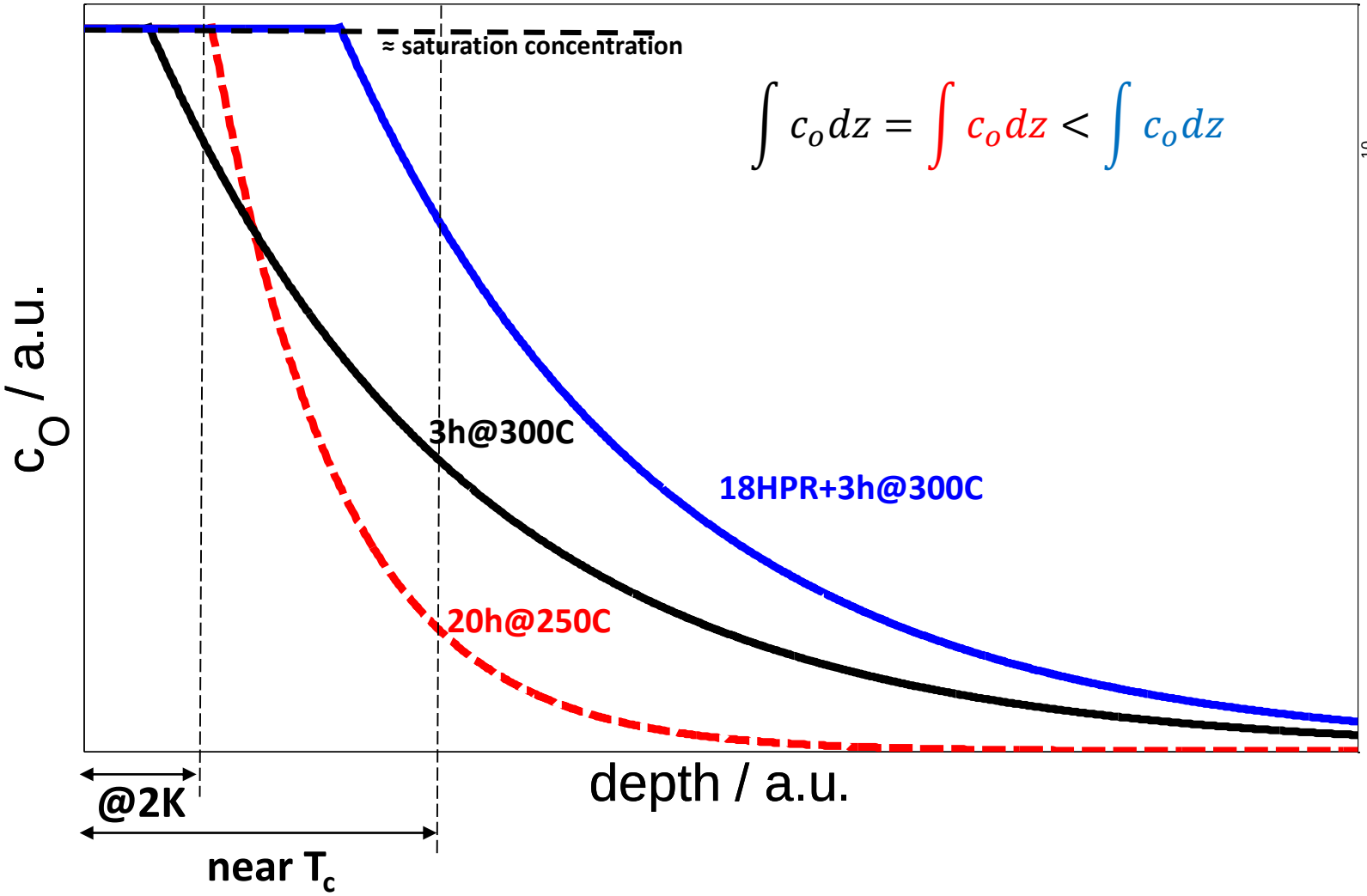

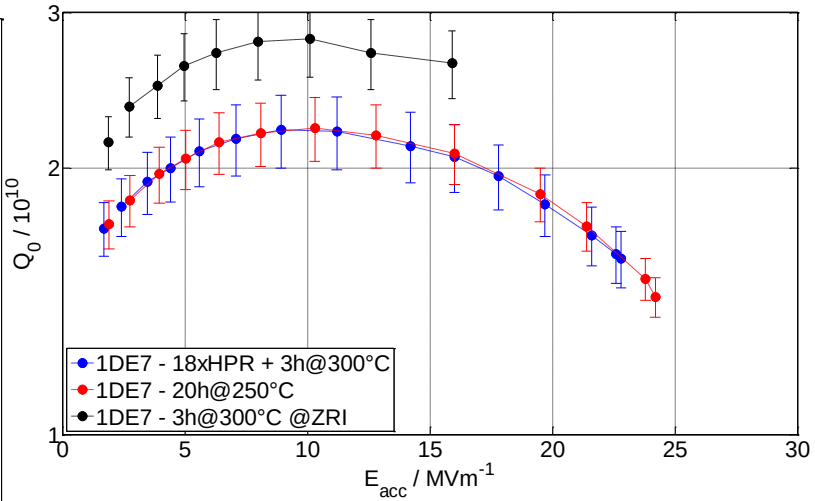

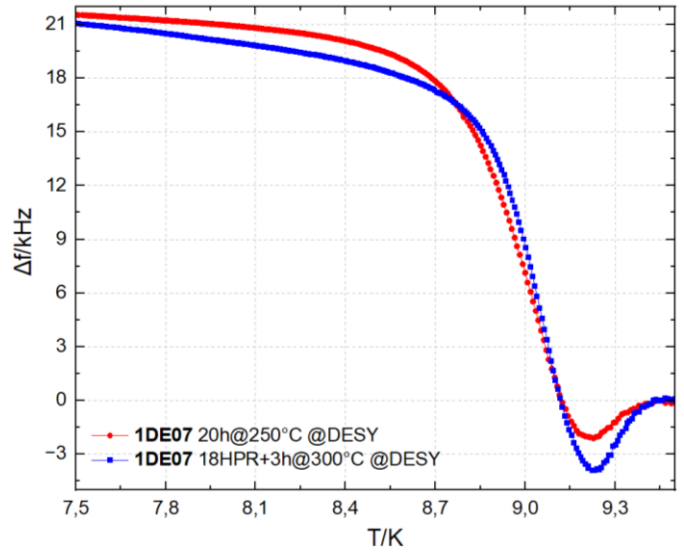

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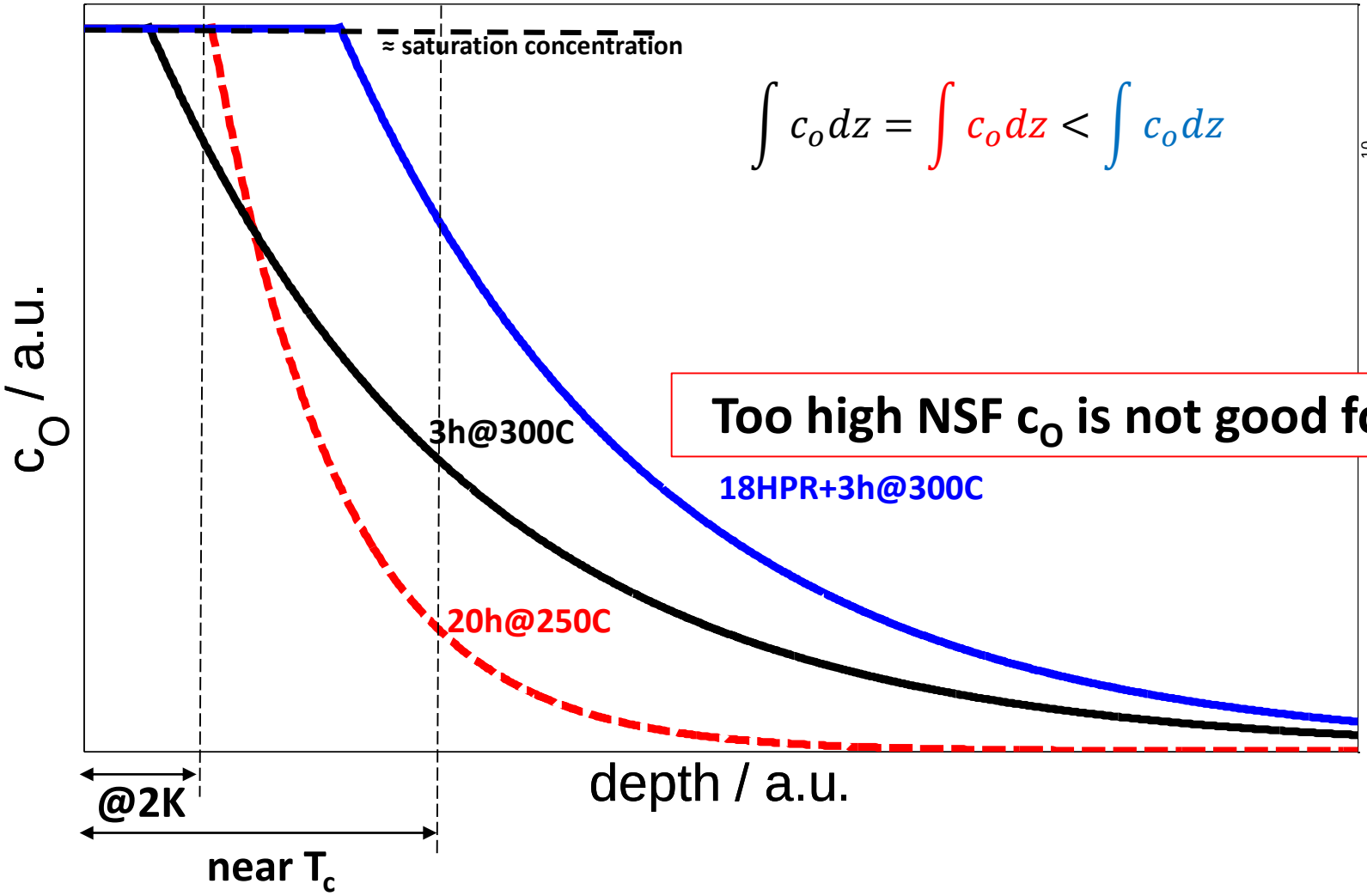

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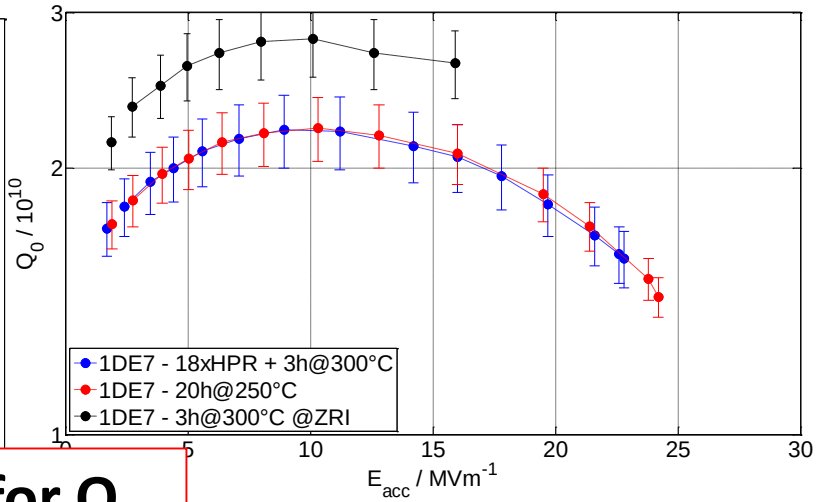

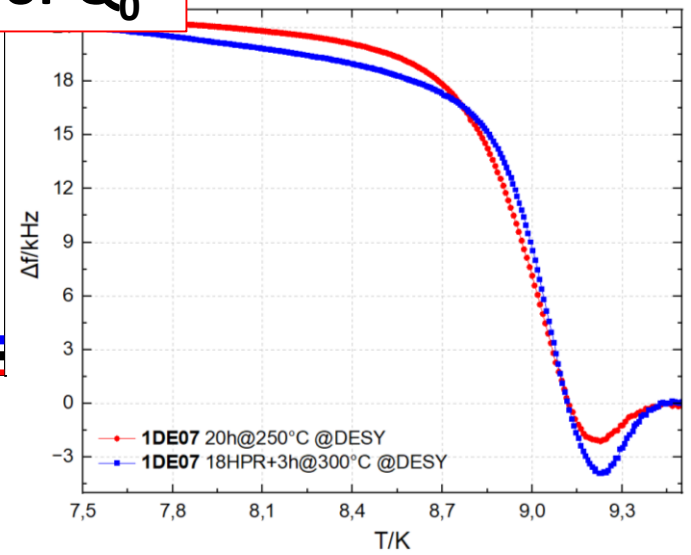

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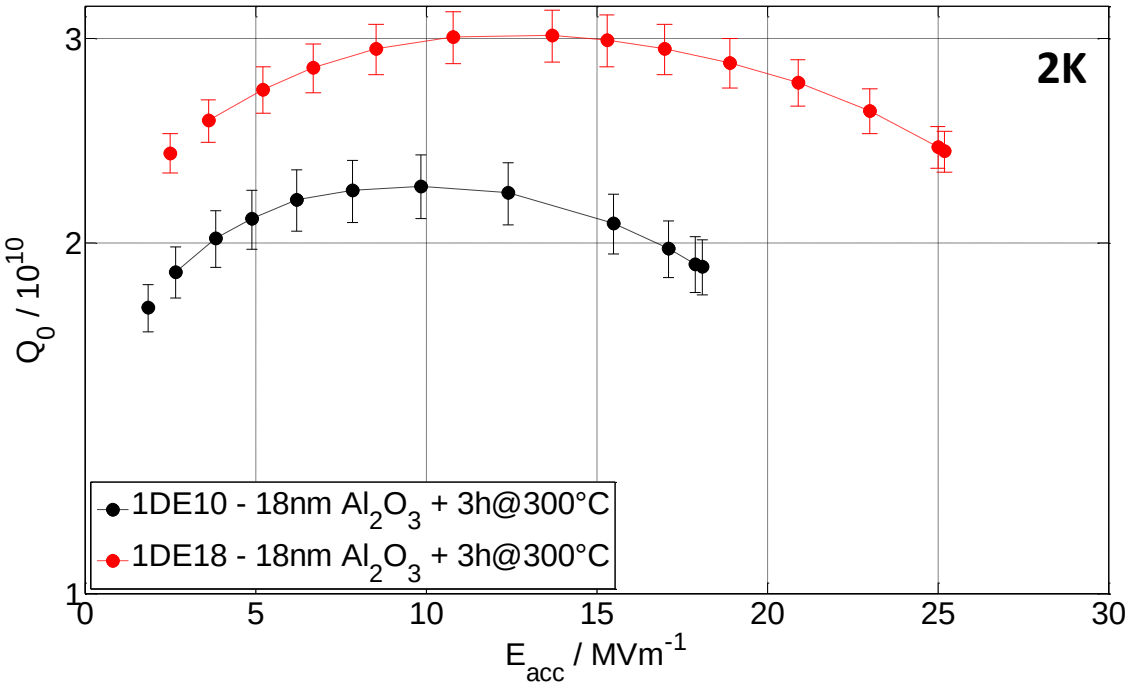

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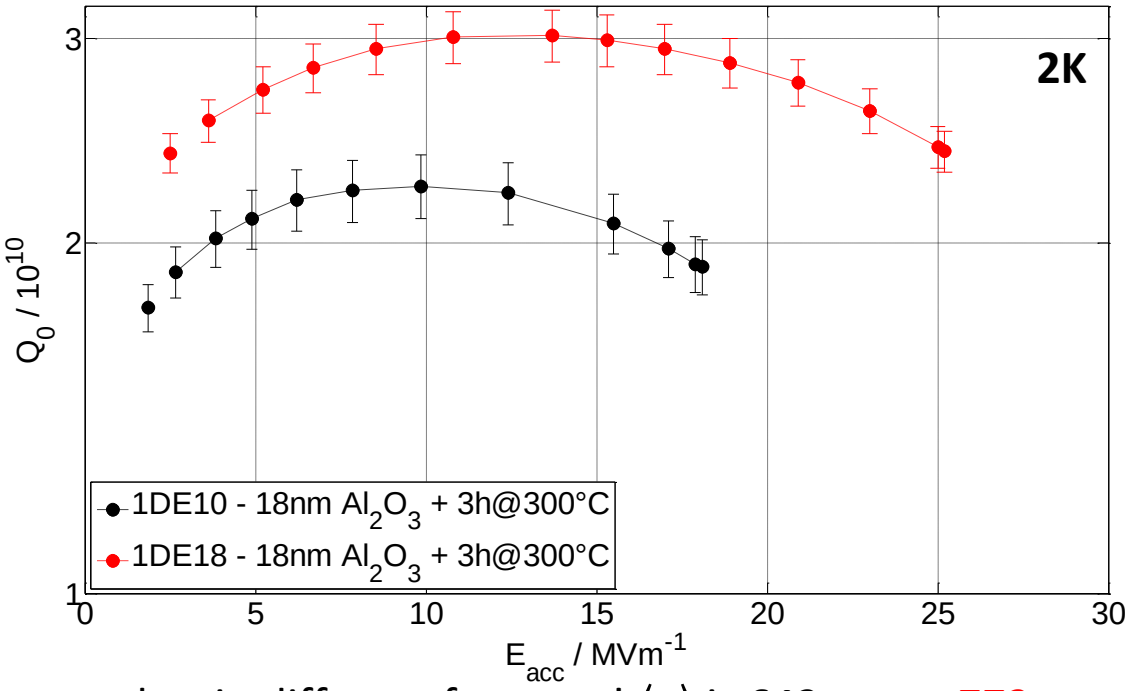

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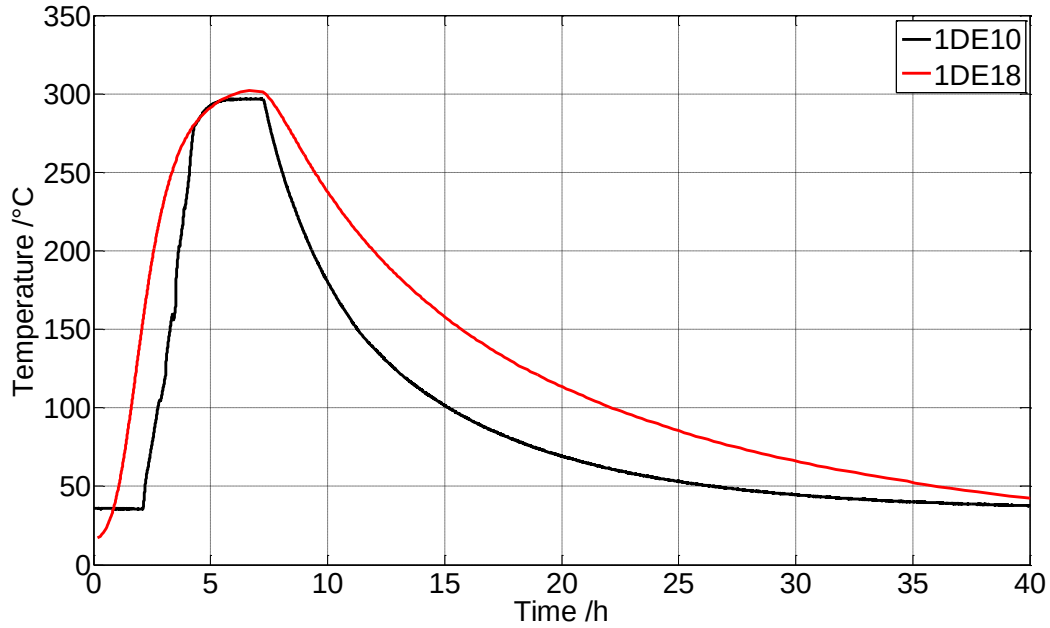

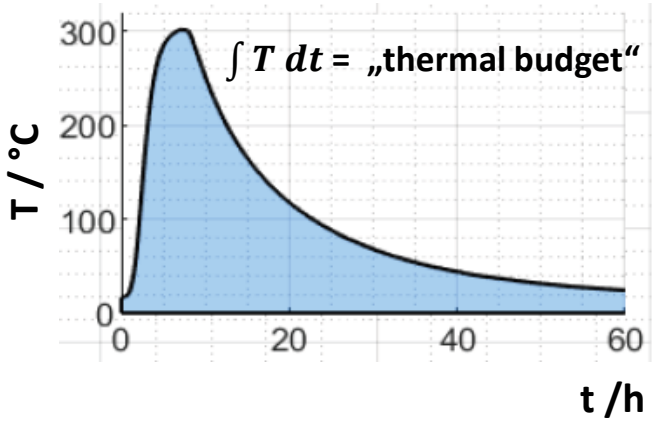

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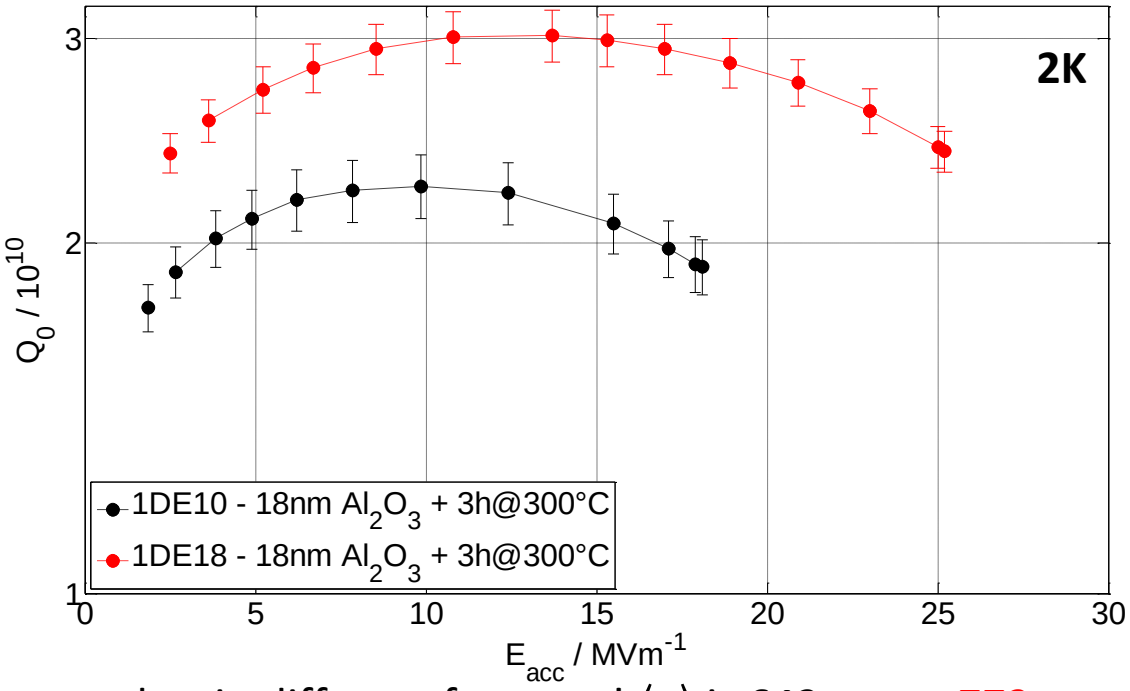

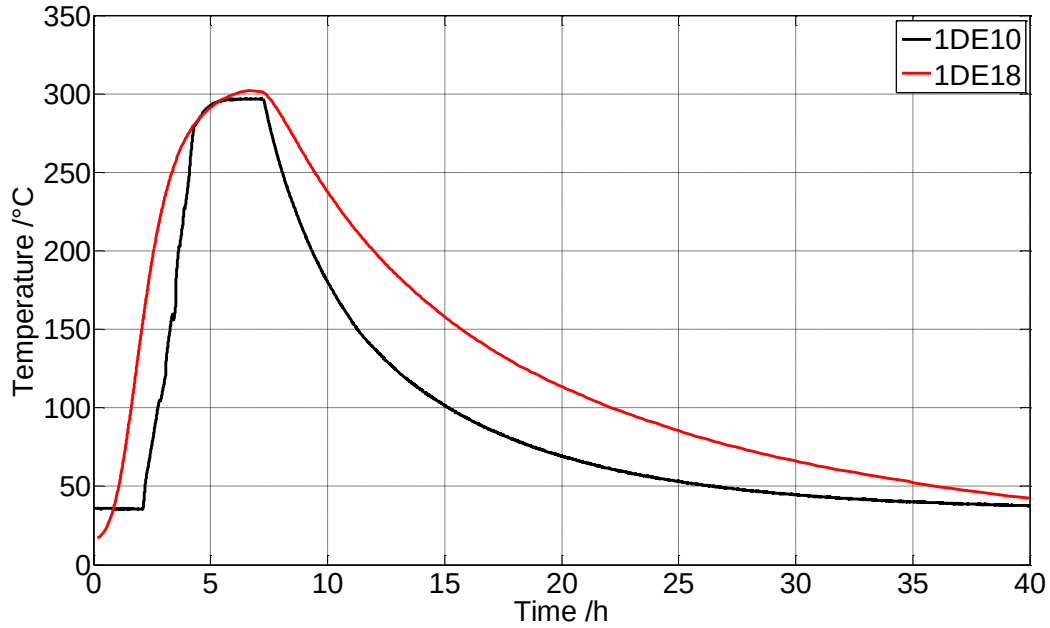

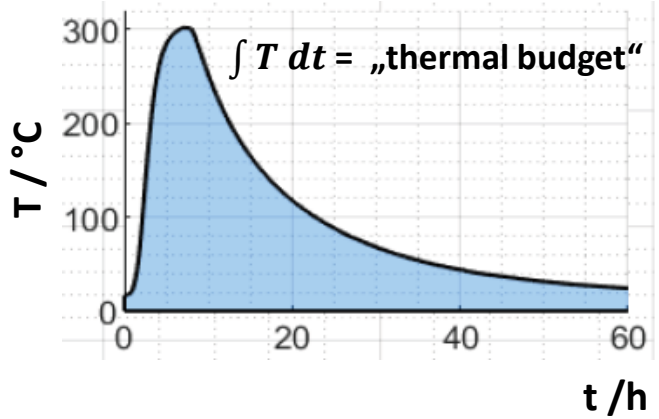

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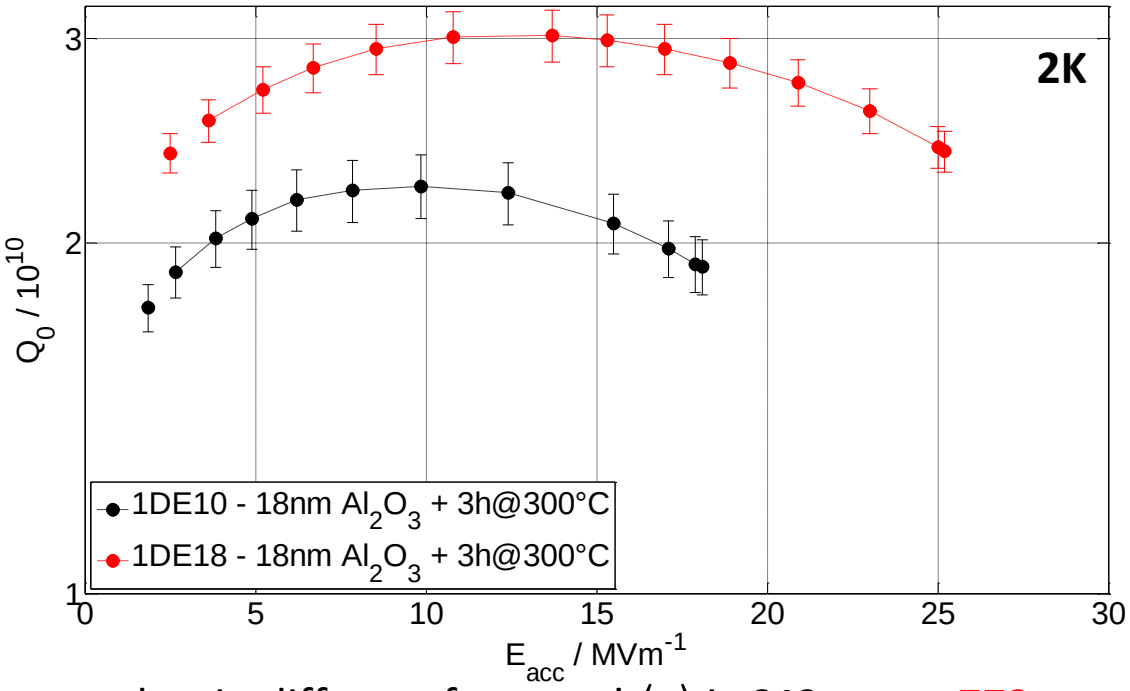

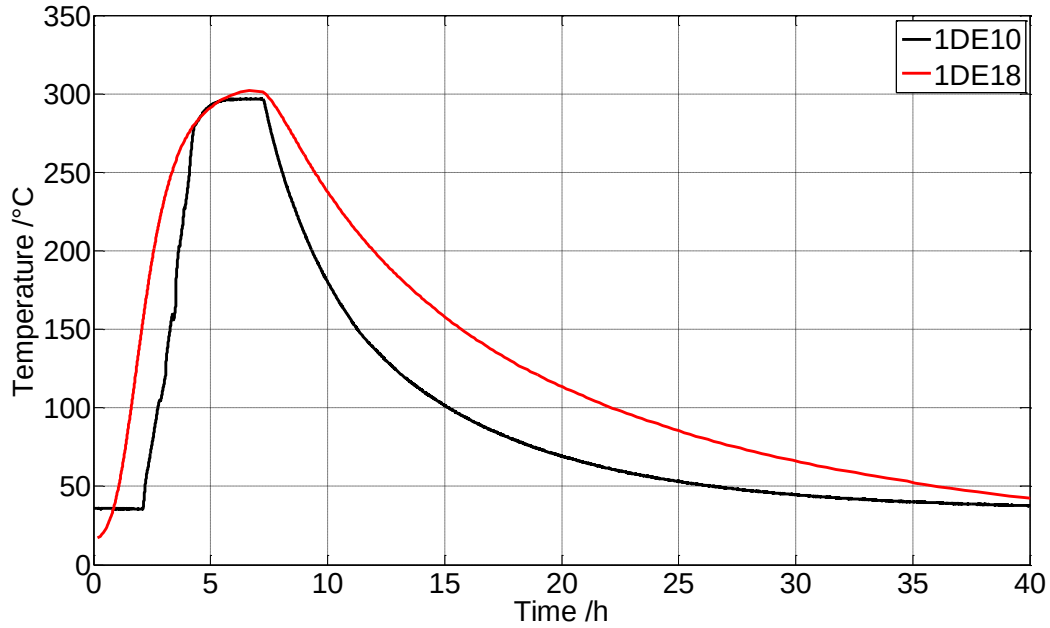

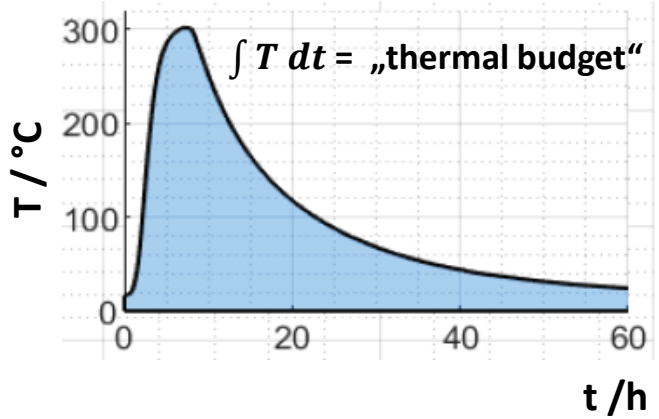

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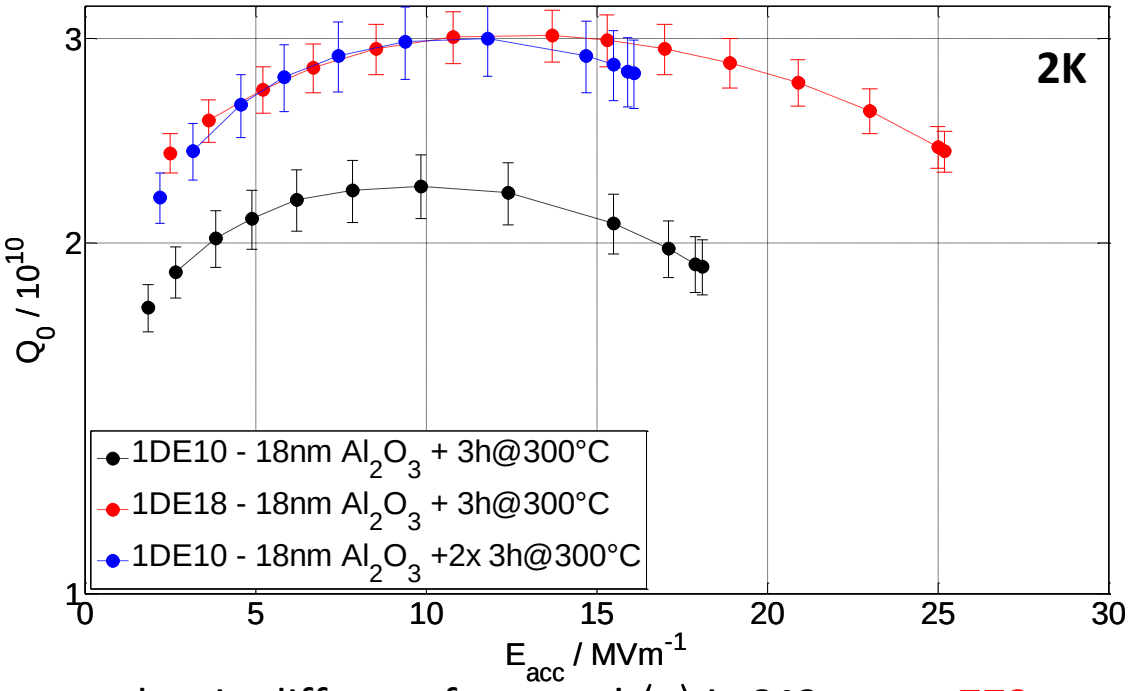

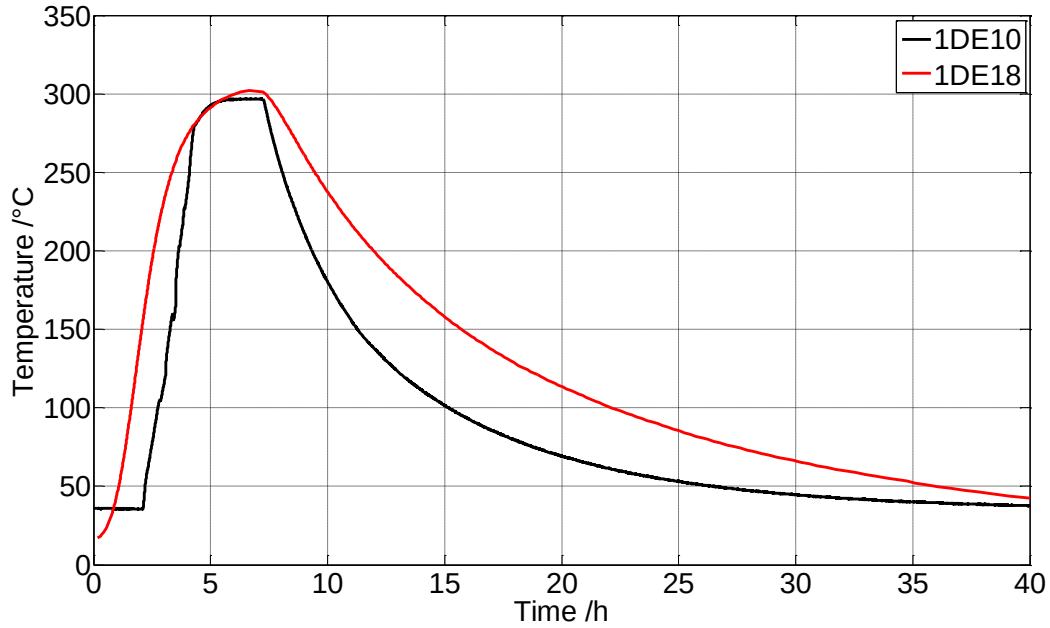

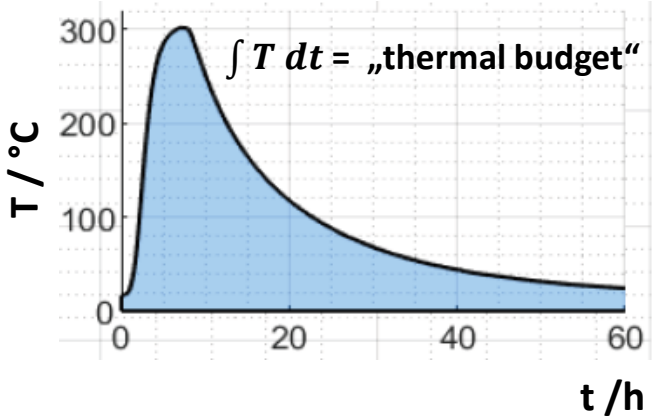

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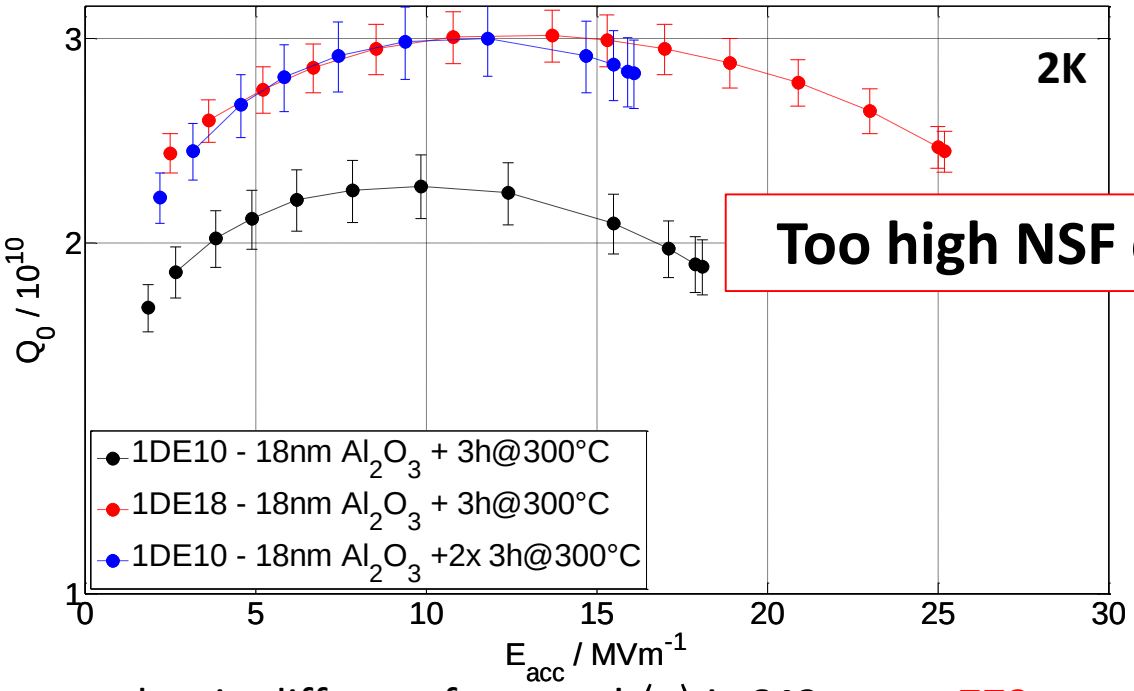

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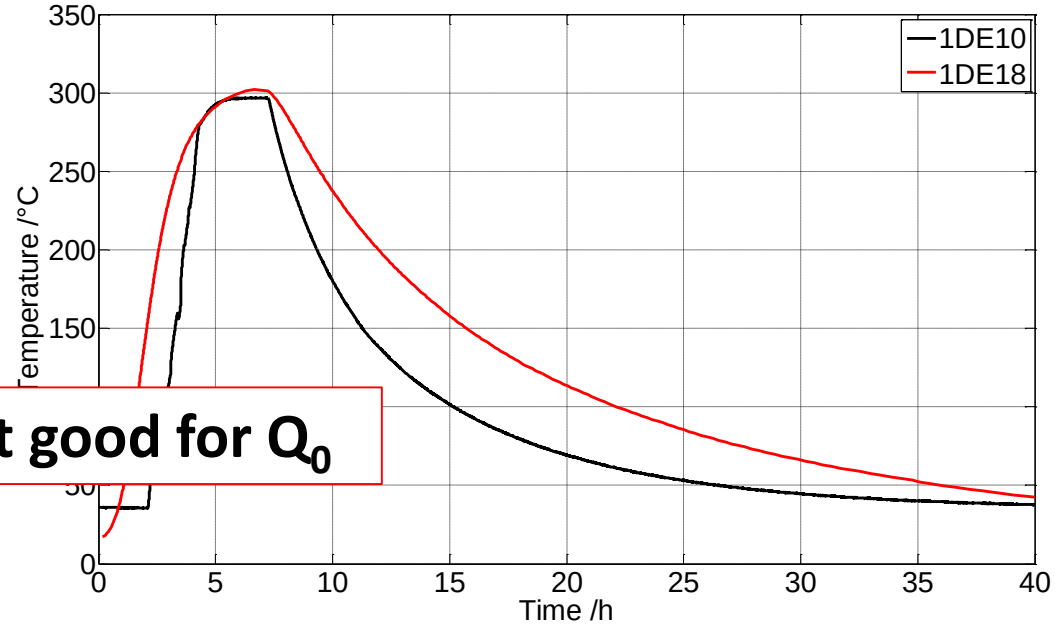

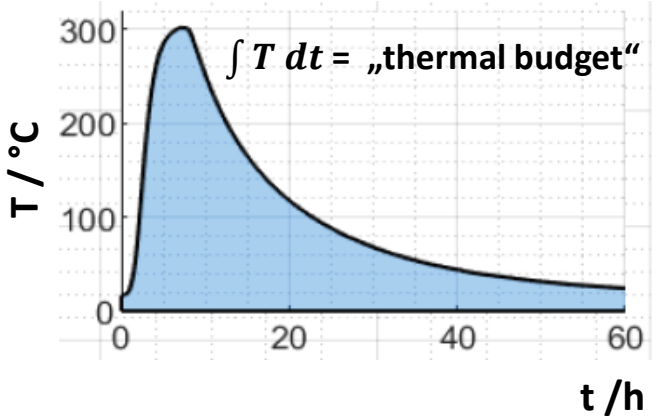

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High thermal budget

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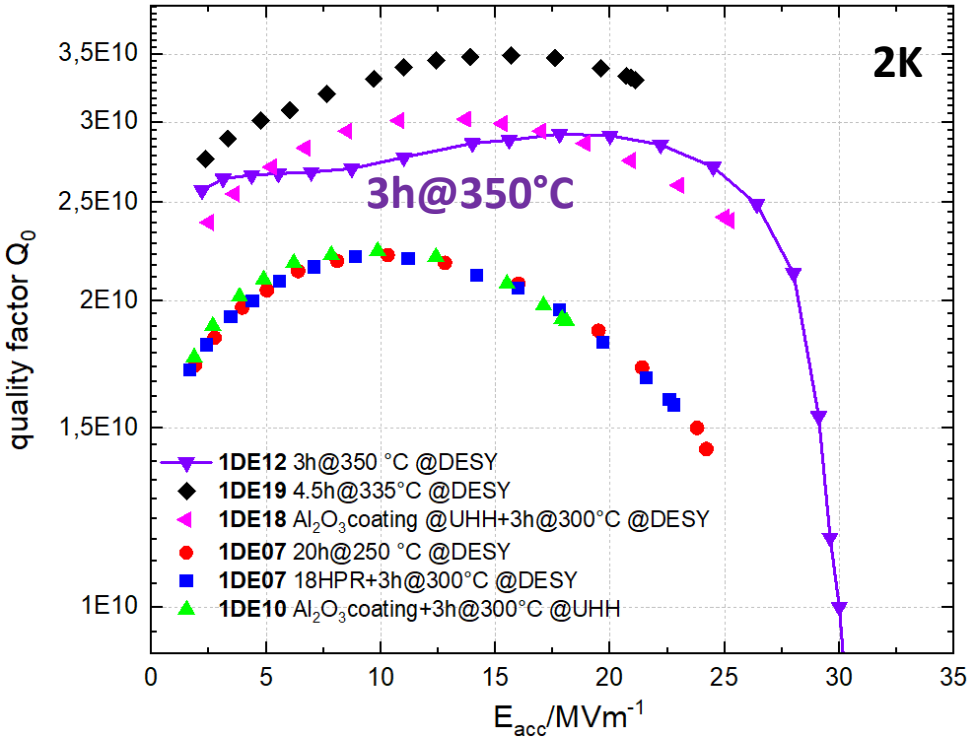

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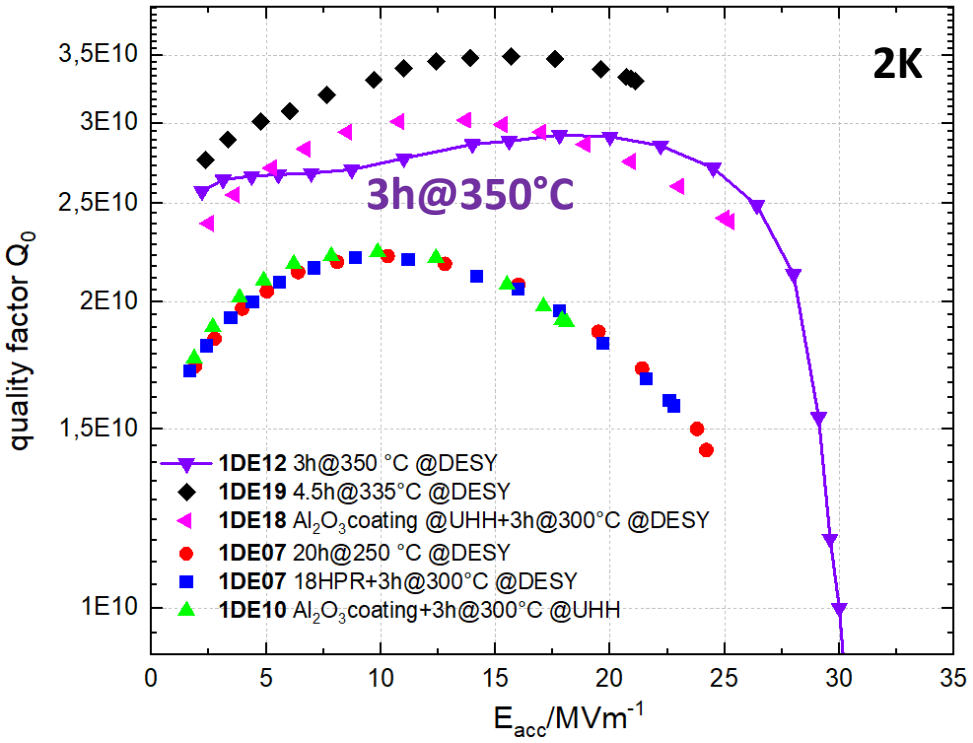

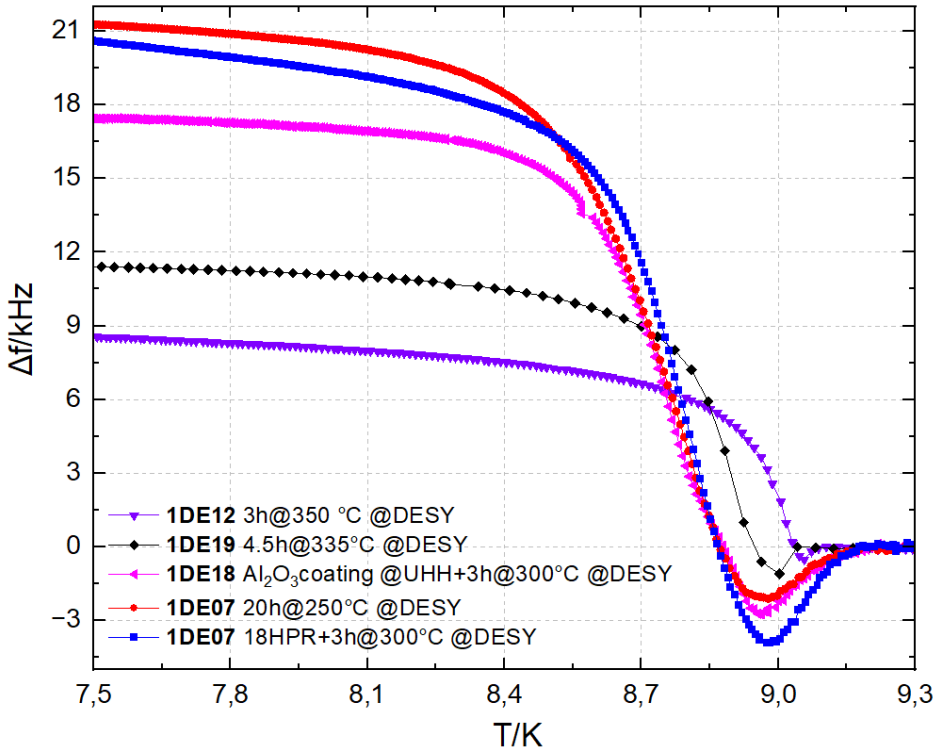

Cavity	Treatment	Δf_{tot}/kHz	Δf_{dip}/kHz
1DE19	4.5h @ 335°C	11.7	1.1
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1DE12	**3h @350°C**	**8.3**	**0.52**

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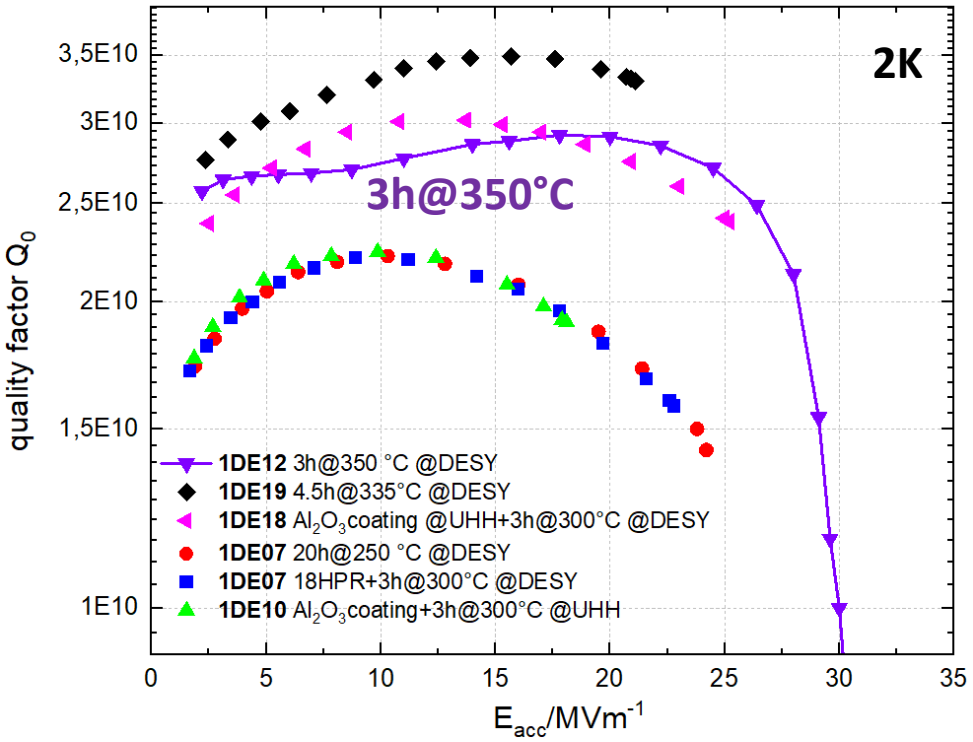

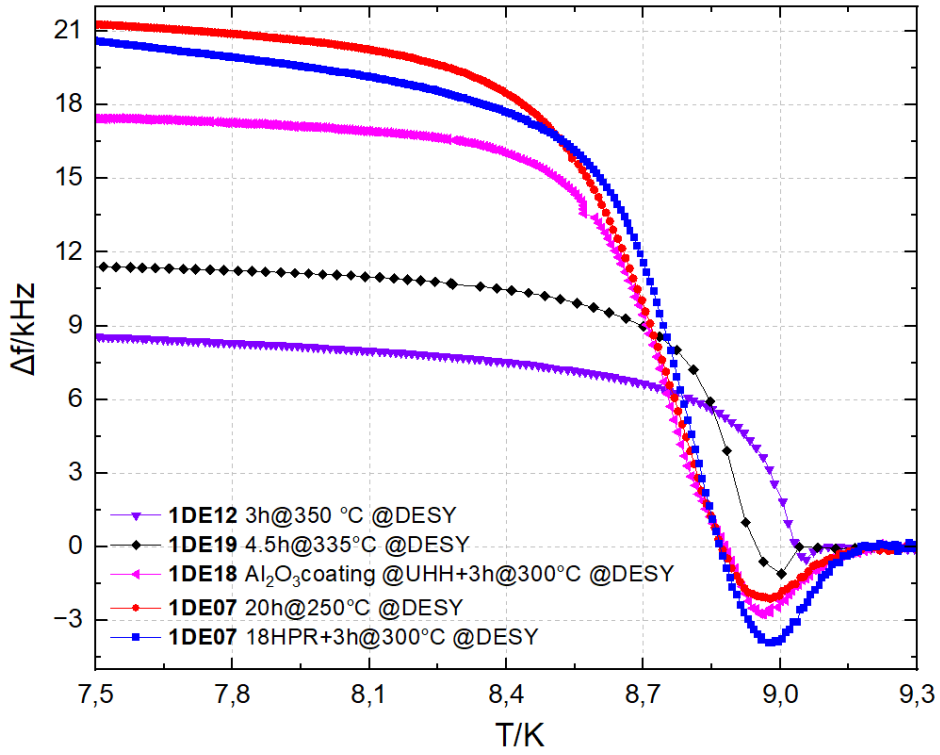

- Diffuse O out of RF layer
  → HFQS reappears and Δf_{tot} / Δf_{dip} decreases again

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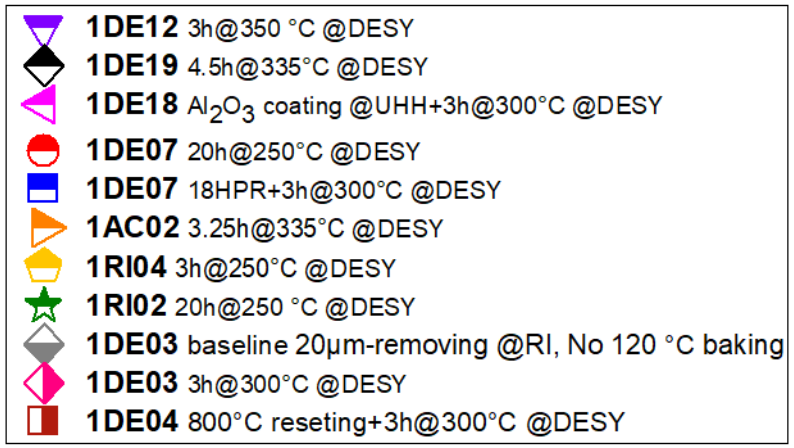

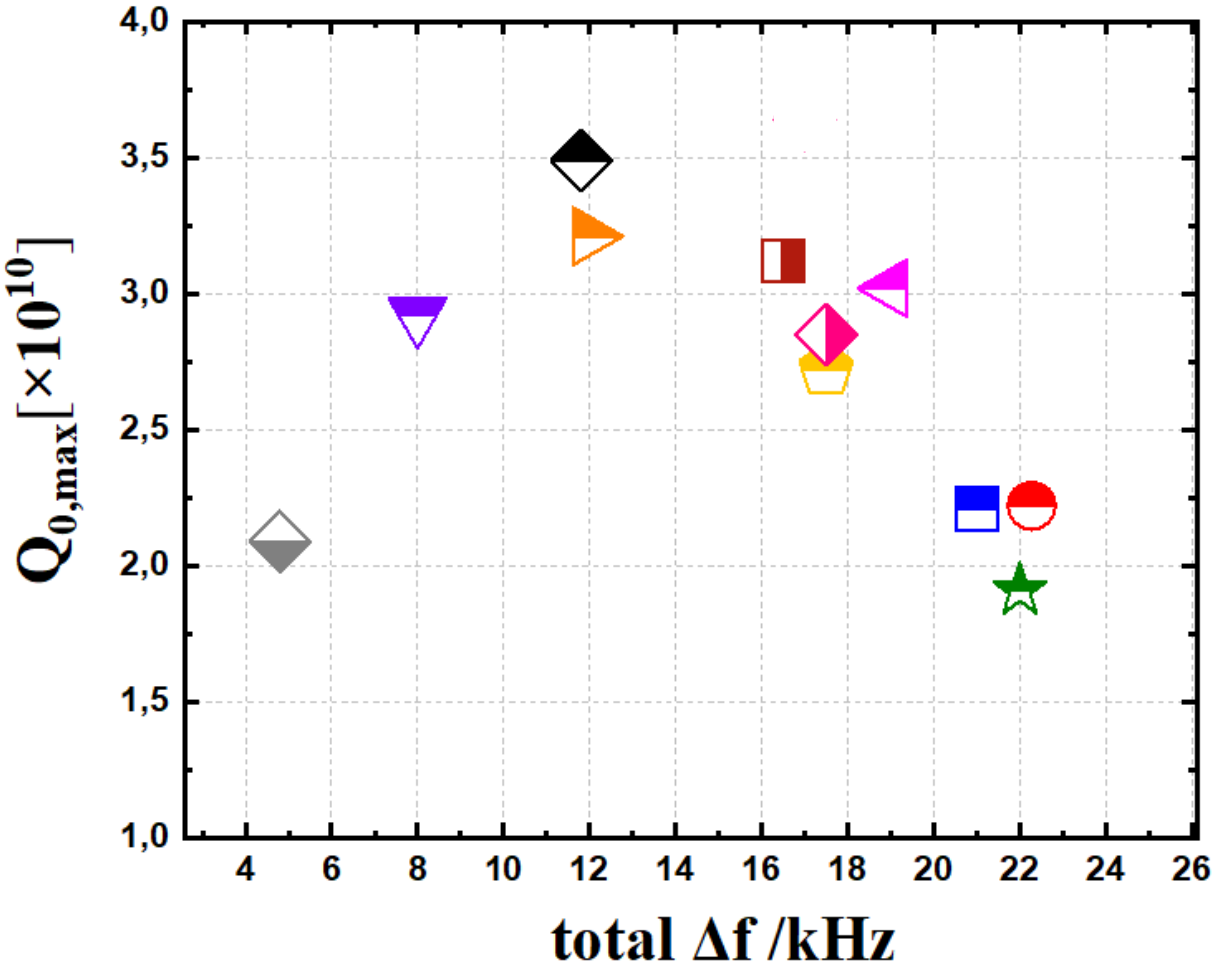

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- Too low c_O leads to HFQS again
  - 1DE12 or every 800°C reset
- Optimal recipe depends on furnace – „thermal budget“
  - 1DE10 vs. 1DE18
- Sweet spot for Q_0 seems to exist – right amount of disorder ?
  - continue investigation & model building (Δf_{tot} vs. Δf_{dip}, E_{acc}, grain mapping)

Thanks…

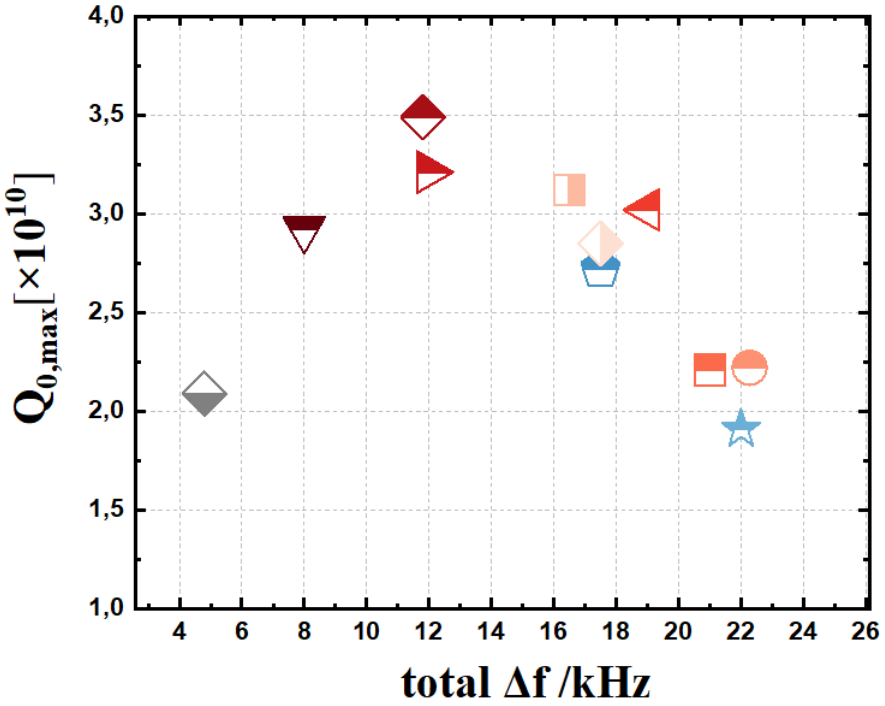
- to **DESY** for the cavity measurements
- to **you** for listening

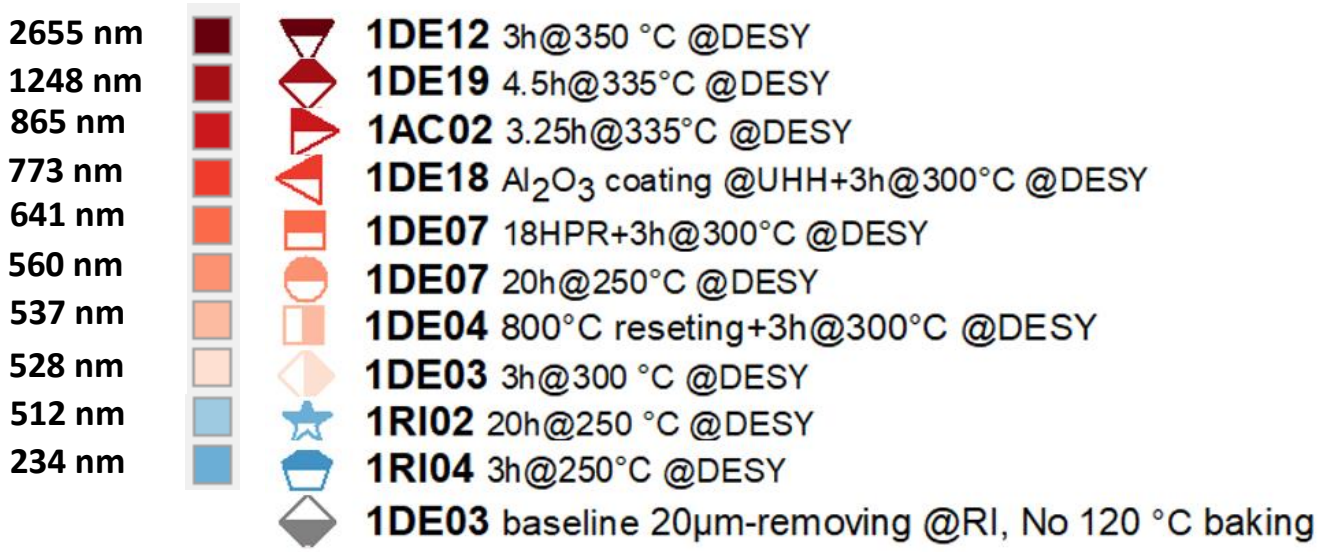
Questions?

Back Up

Correlation with thermal budget?

Assumed Δf is depends c_O …
and we know that NSF c_O goes down with larger thermal budget / larger $\langle z \rangle$ …
some correlation of Q_0 with $\langle z \rangle$ expected as well – yet weaker as Fick's law does not accomodate uneven GB diffusion / saturation effects



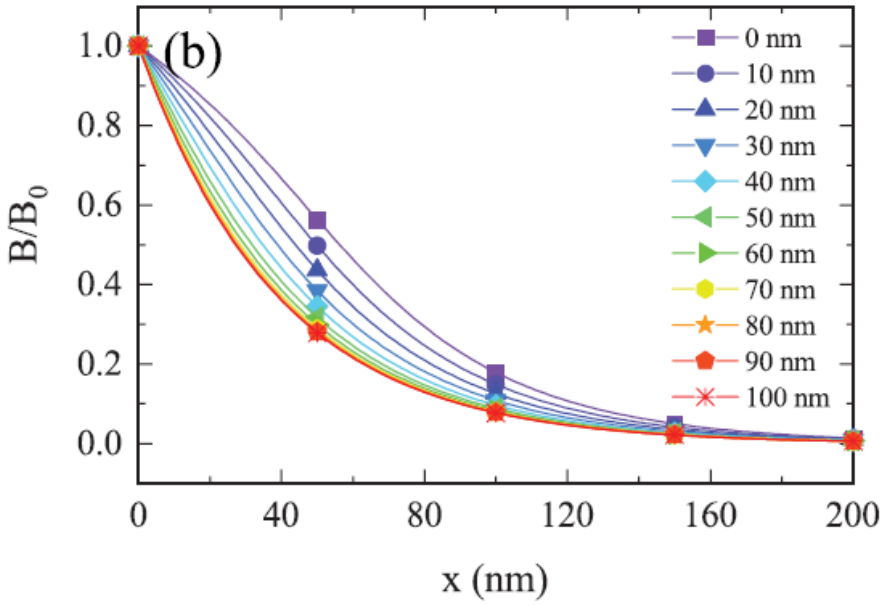


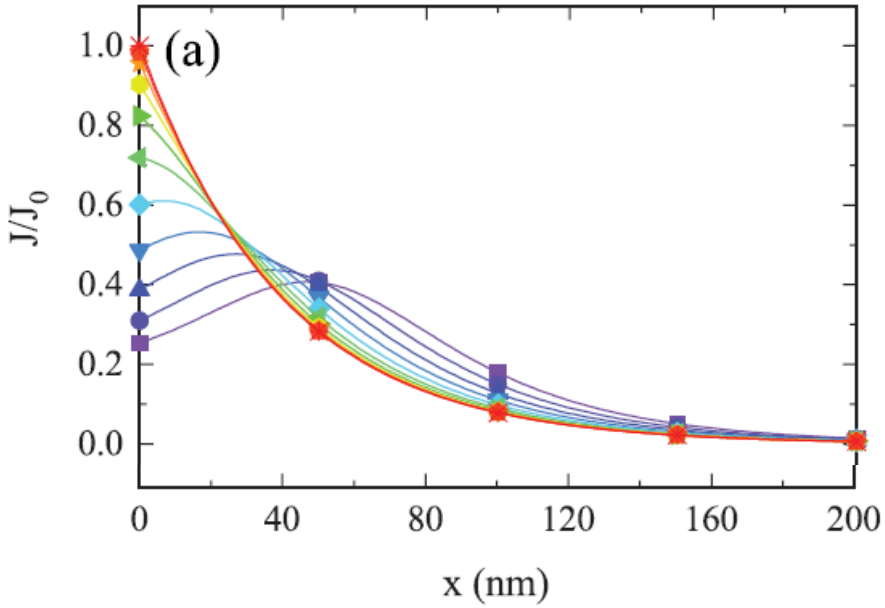
Current Redistribution

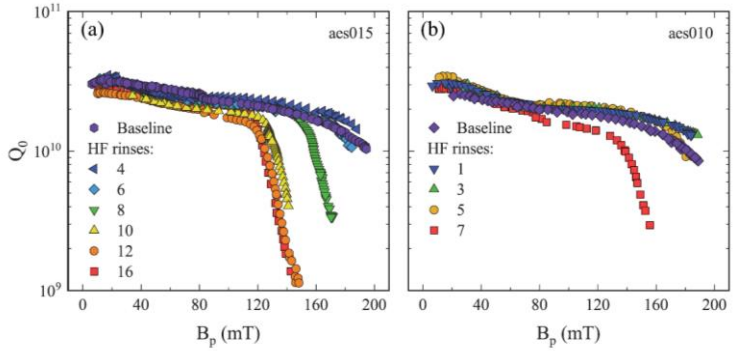
[Checchin, M. et al., Appl. Phys. Lett. 117, 032601 (2020)]
[Pambianchi, M. et al., Phys. Rev. B 50, 13659]

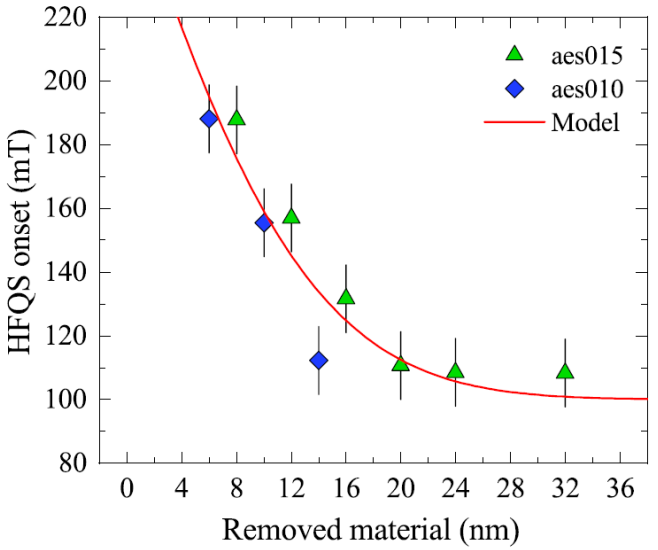
$$\lambda^2 B''(x) + 2\lambda\lambda' B'(x) - B(x) = 0.$$

$$\lambda(x) = (\lambda_s - \lambda_0)\mathrm{Erfc}\left[\frac{x}{\delta}\right] + \lambda_0,$$



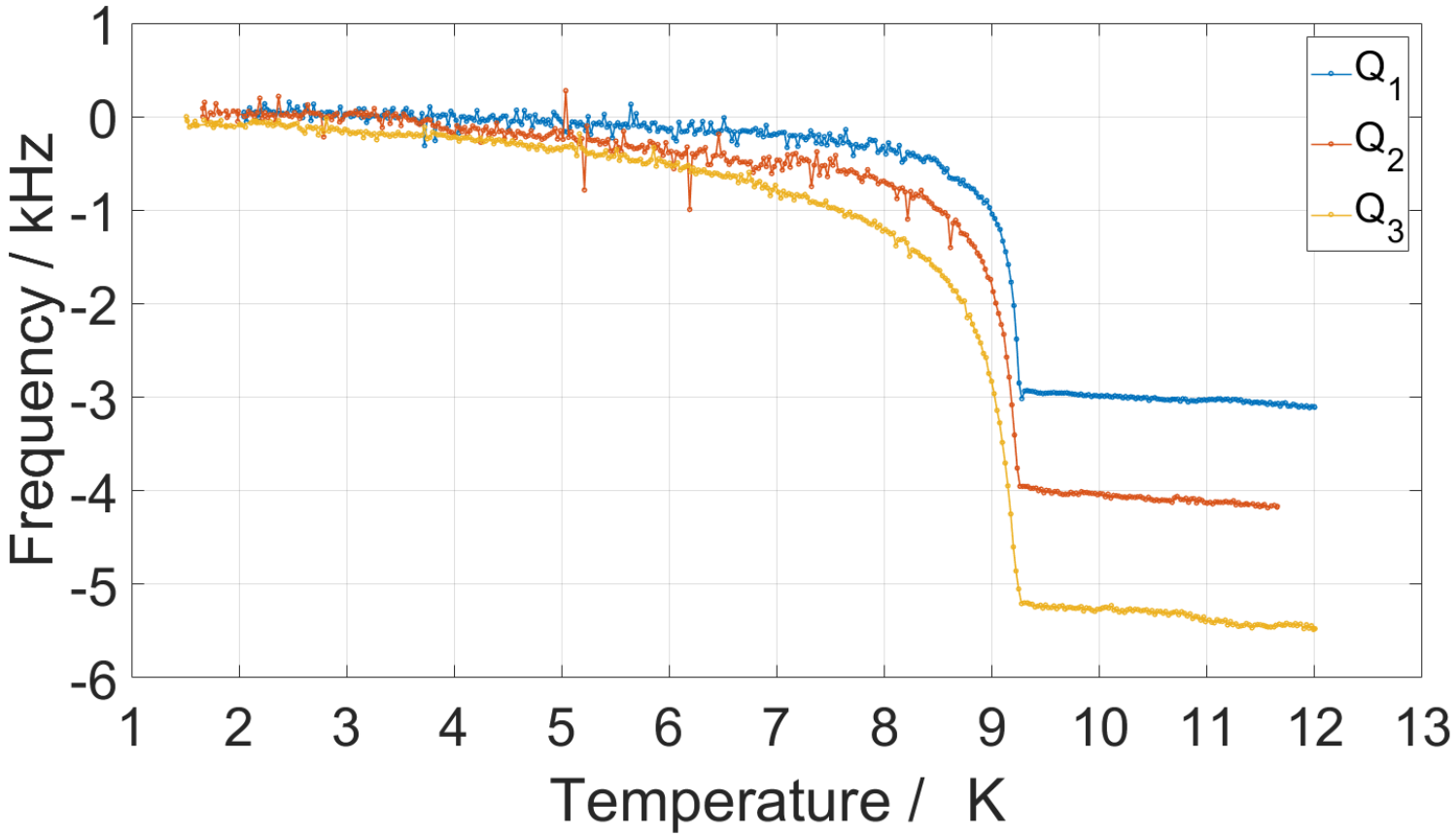






Consequence:
Currents shifted away from the surface where “lossy mechanism(s)” occur

Frequency shift is frequency dependent

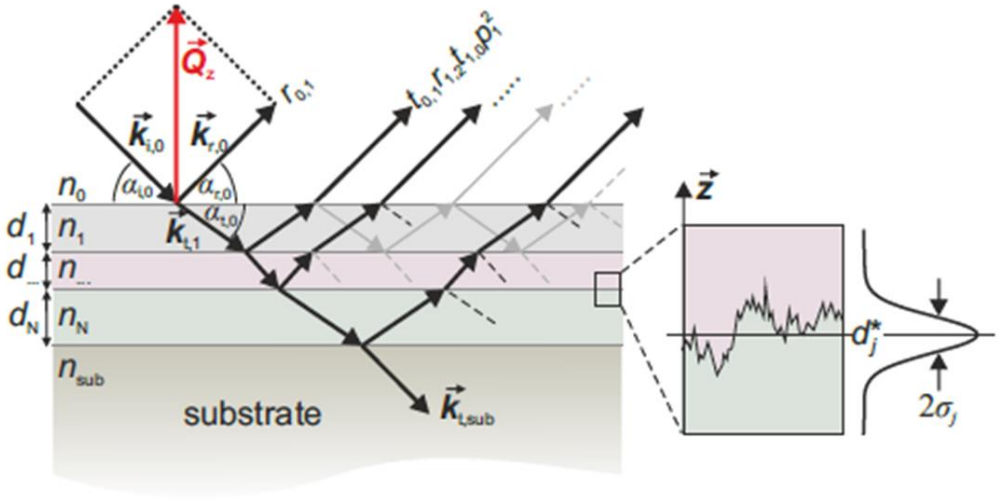


- Q_n = n x 433MHz
- Lower frequency f_{op} ⟶ lower Δf_{tot}
- That is because Γ is frequency dependent
- If the dip is caused by current redistribution ⟶ Δf_{dip} should depend on f_{op} as well

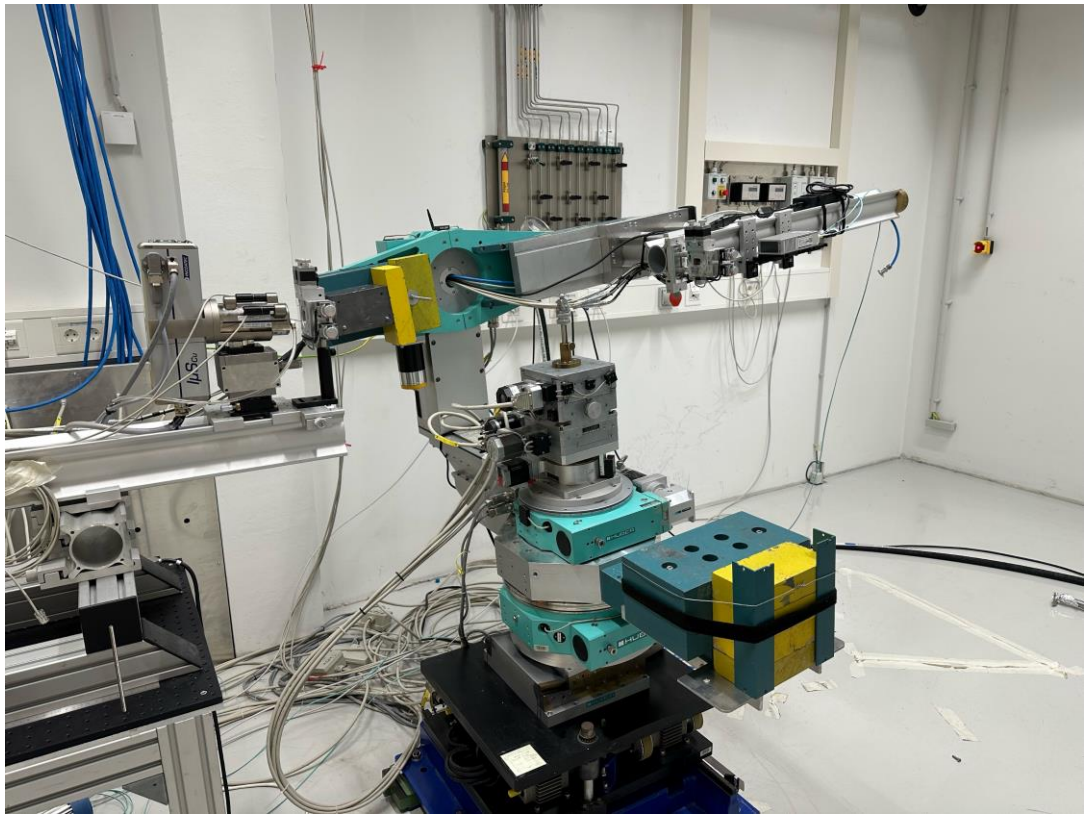
X-Ray Reflectivity (XRR)

Non-destructive method of analysis

Weak scattering cross-section --> large penetration depth



[Dissertation Uta Hejral, 2015]



101 on XRR: Information from the curve