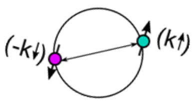
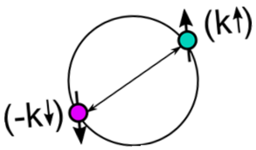
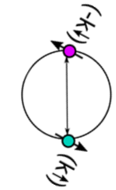
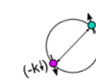
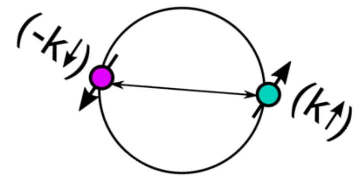




A Three-Fluid Model of Dissipation at Surfaces in Superconducting Radiofrequency Cavities





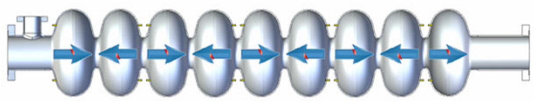


11am Tuesday June 27th, 2023; SRF 2023 Grand Rapids, MI

Michelle M. Kelley, S. Deyo, N. Sitaraman, T. Oseroff, D. B. Liarte, M. Liepe, J. P. Sethna, T. A. Arias (Cornell University)

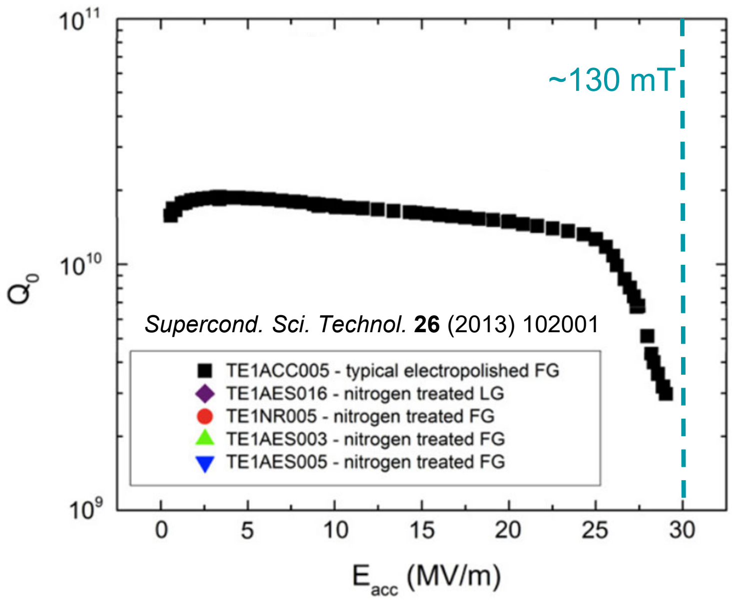
The Center for BRIGHT BEAMS
A National Science Foundation Science & Technology Center

Field dependence of efficiency (quality factor)



Superconducting radiofrequency (SRF) cavity

$$Q \equiv 2\pi \frac{\text{energy stored}}{\text{energy dissipated per RF cycle}}$$



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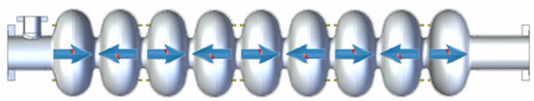

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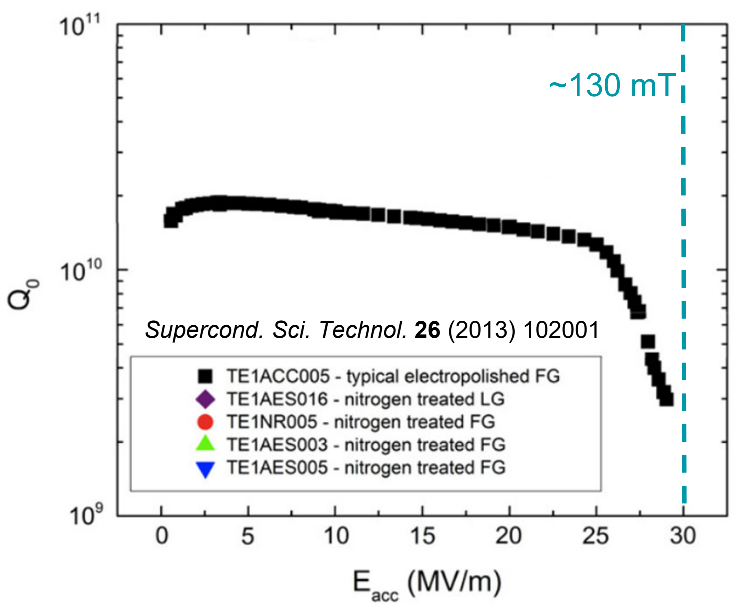

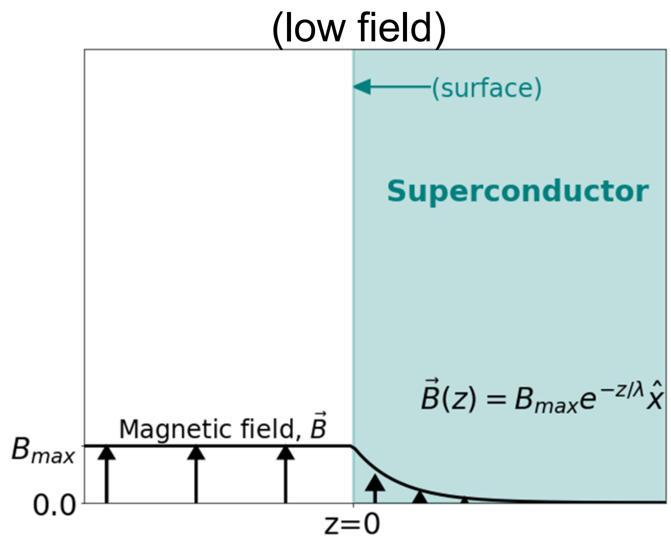

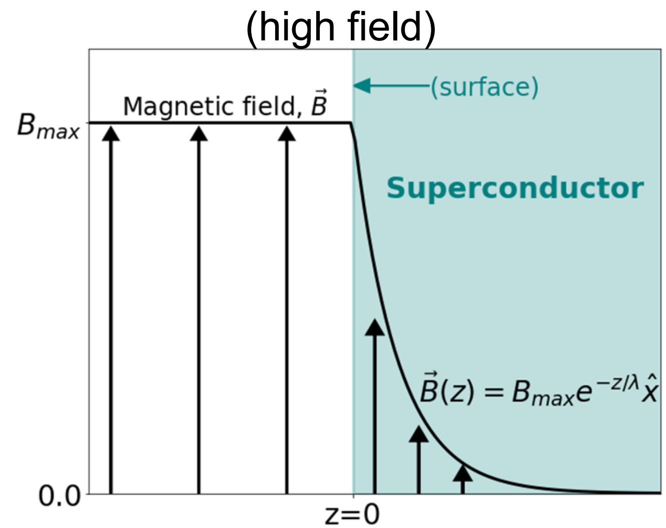

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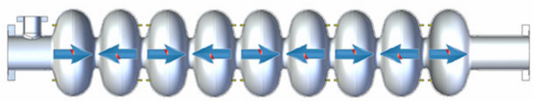

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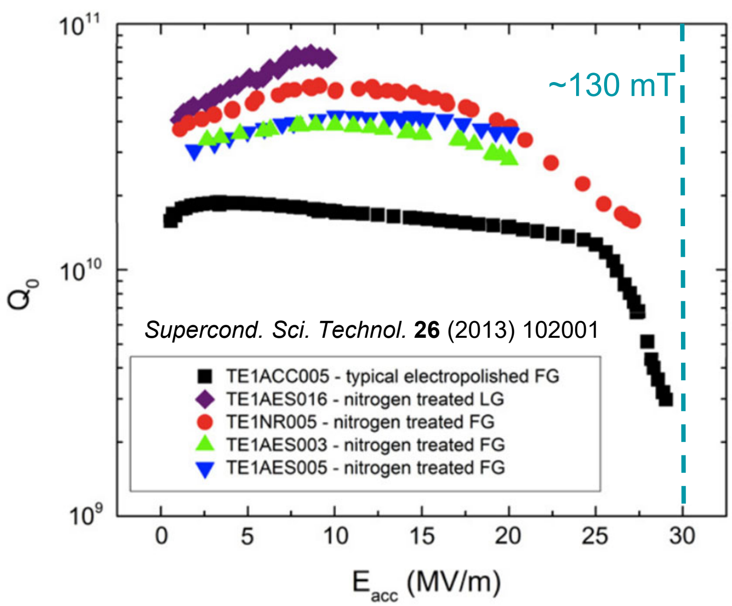

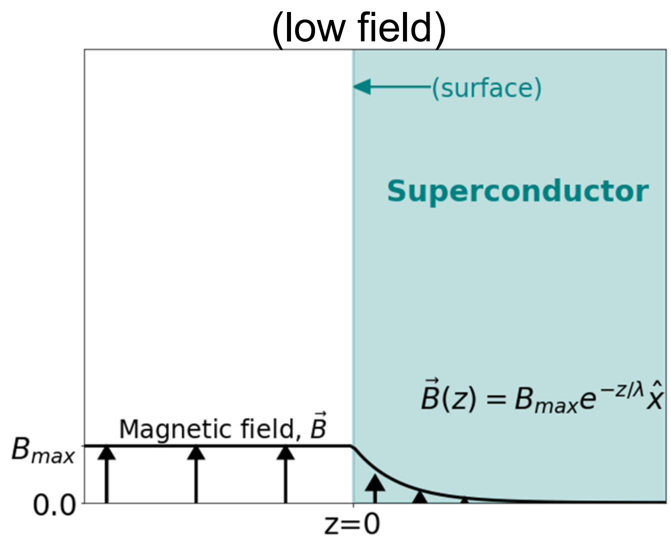

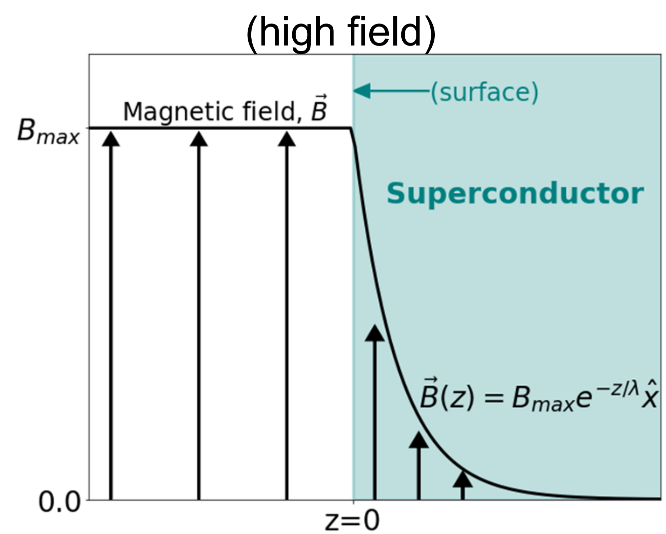

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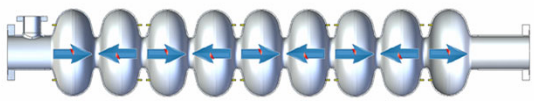

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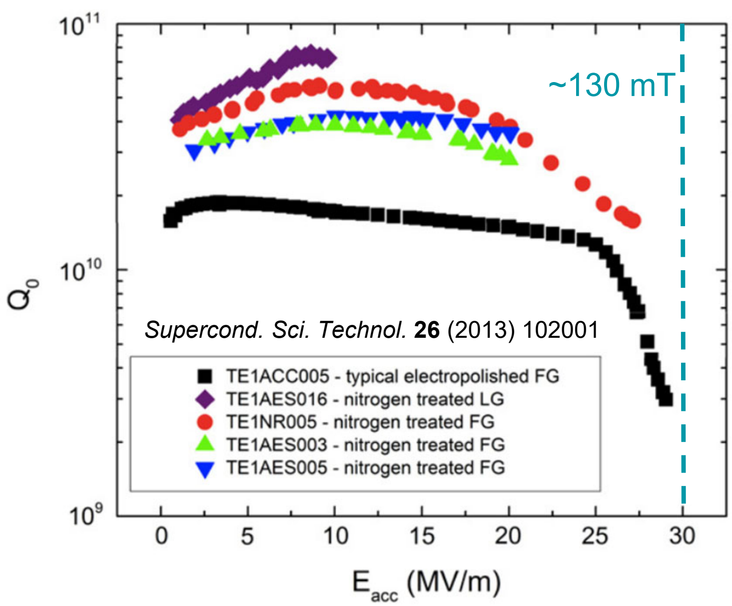

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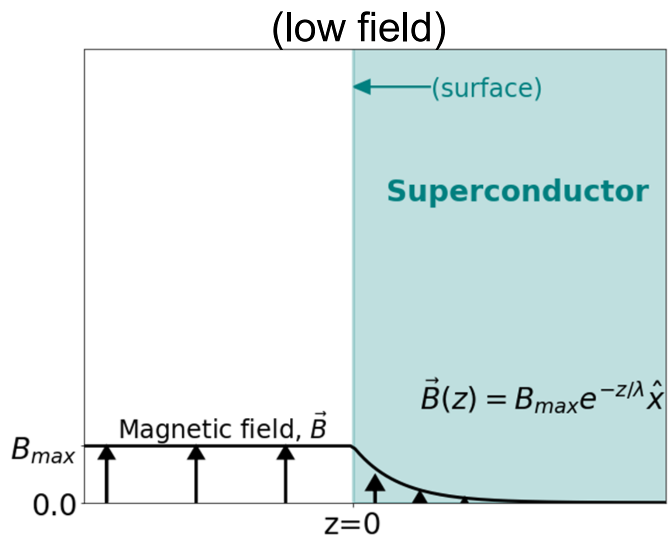
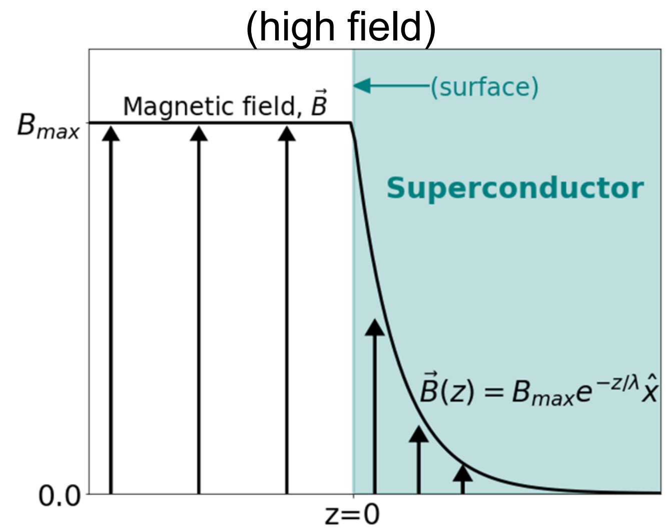
How can stronger fields increase the efficiency of an SRF cavity???





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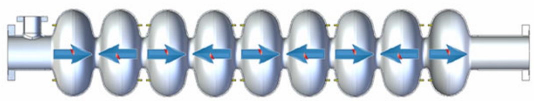

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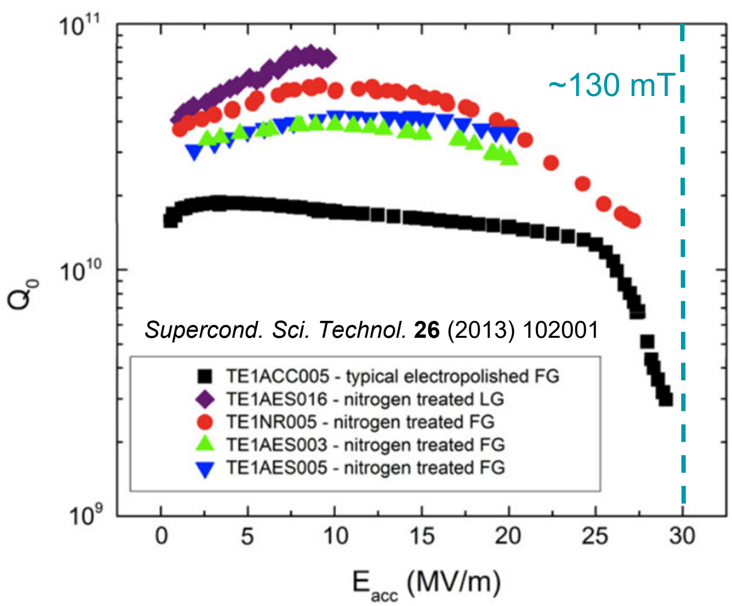

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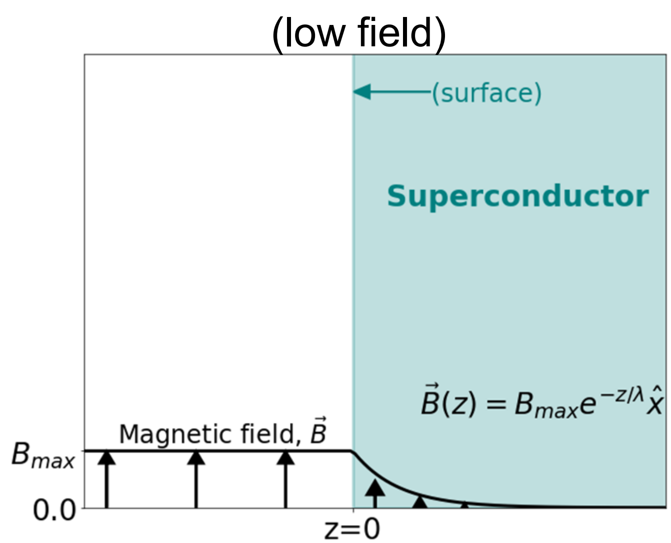

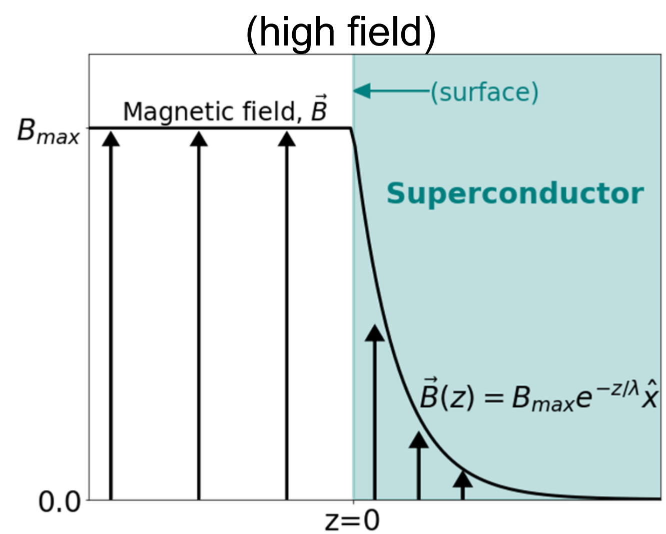

→ need to study dissipation at superconducting surfaces

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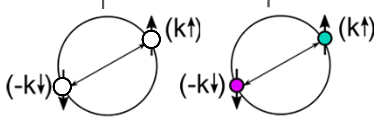
Superconducting RF dissipation & Bogoliubov quasiparticles

Bogoliubov transformation

$$\Psi(r\uparrow) = \sum_n \left(\gamma_{n\uparrow} u_n(r) + \gamma^\dagger_{n\downarrow} v^*_n(r)\right)$$

$$|u|^2 + |v|^2 = 1$$



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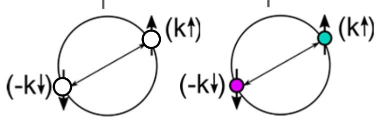

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self-consistent field method

$$(H_e + U)u + \Delta v = Eu$$
$$-(H_e^* + U)v + \Delta^* u = Ev$$

$$U = -V \sum_n |u_n|^2 f_n + |v_n|^2 (1 - f_n)$$

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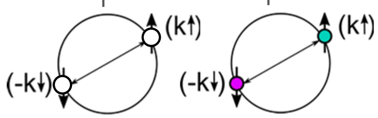

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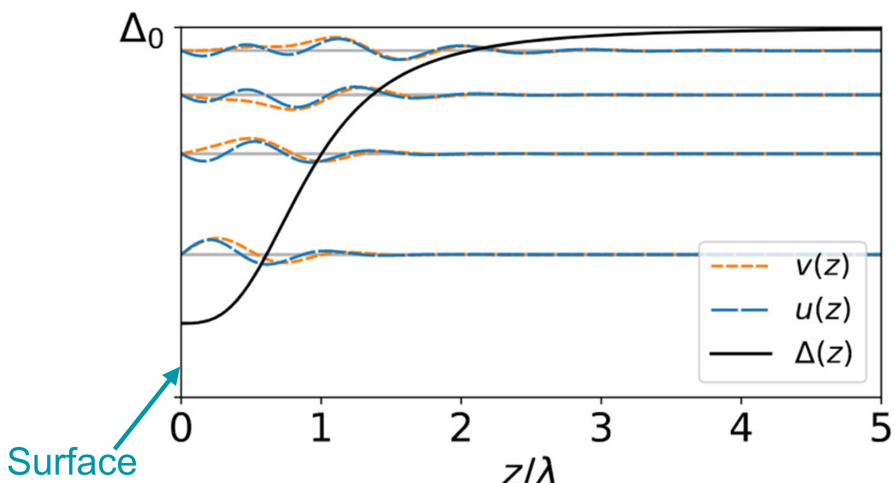
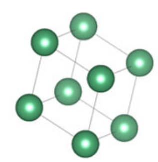
Solve for spatially inhomogeneous energy gap, Δ(z)





$\lambda_{\mathrm{Nb}} \sim 40$ nm $\gg$ ~0.33 nm

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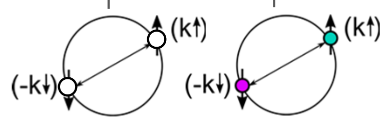

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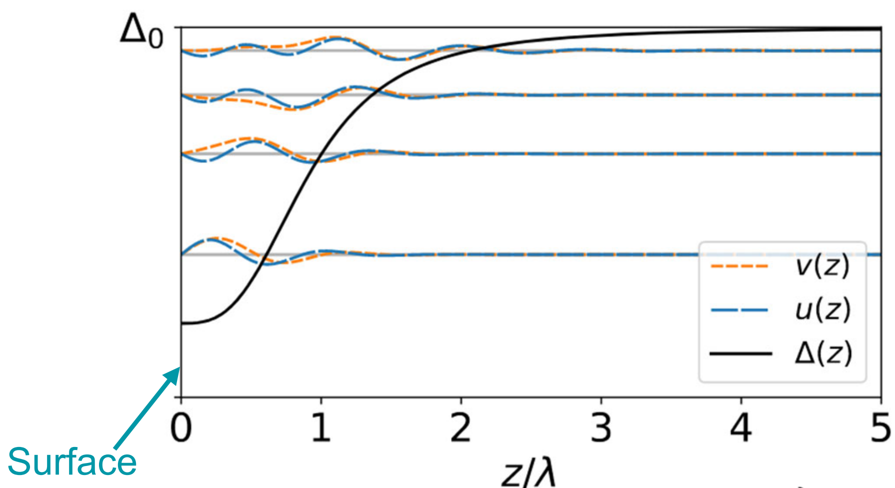

Ohmic dissipation

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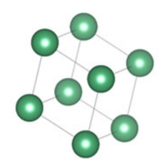

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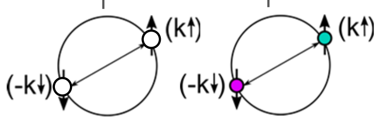

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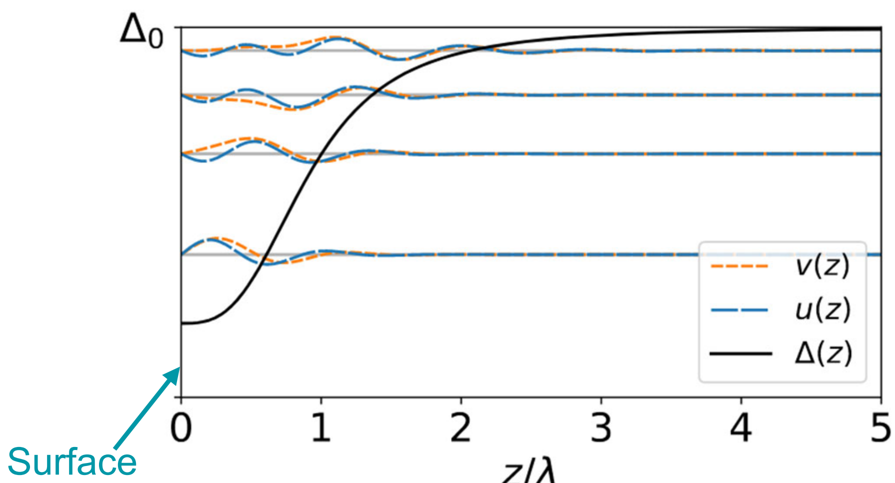

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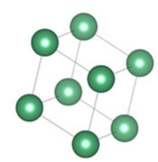

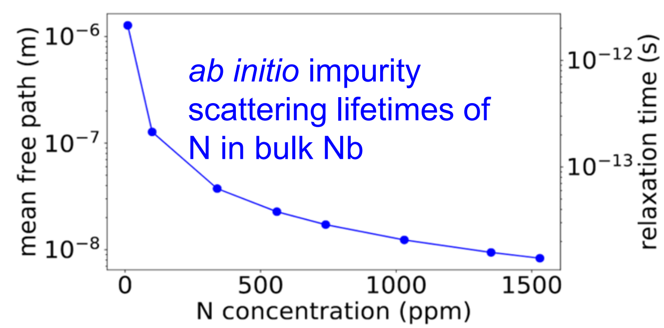

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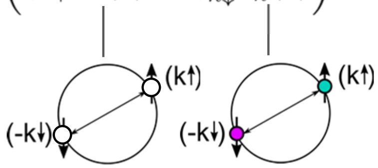

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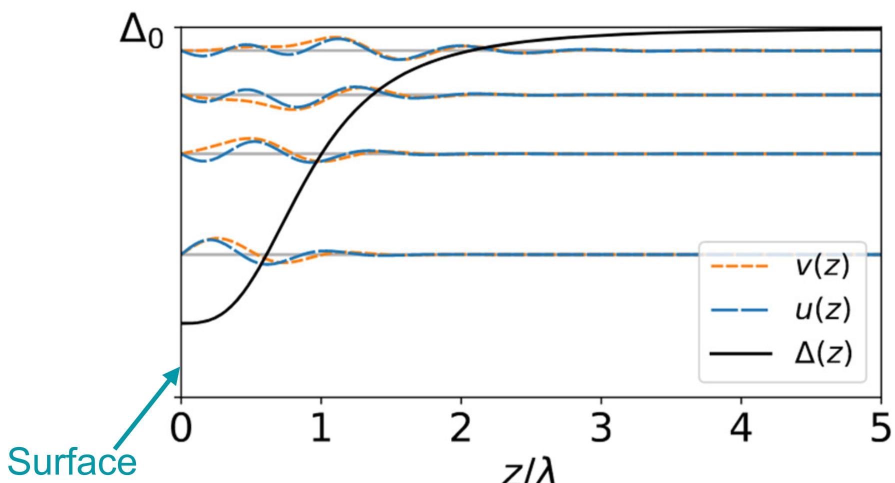

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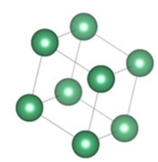

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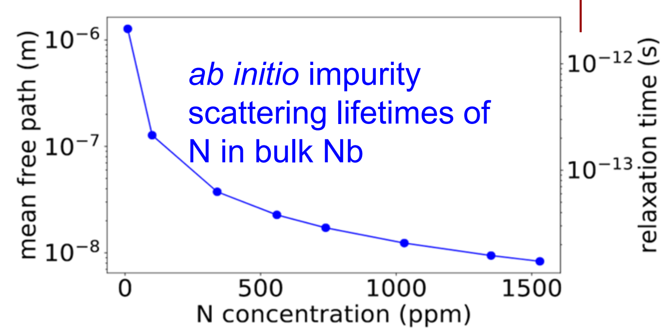
much faster than RF period (~1 ns)



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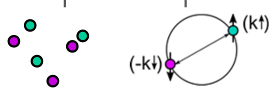
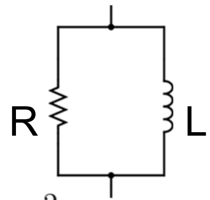
A “three”-fluid model with Bogoliubov quasiparticles

Two-fluid model

$$n_{\text{tot}} = n_n + n_s$$





$$\sigma = \frac{n_n e^2 \tau}{m} + i\frac{n_s e^2}{m\omega}$$

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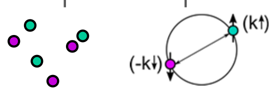

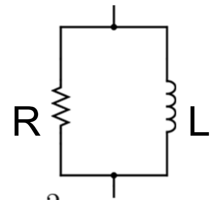

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BCS prediction

$$E_i = \sqrt{\xi_i^2 + \Delta^2}$$

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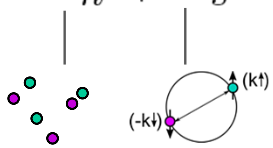

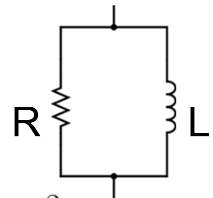

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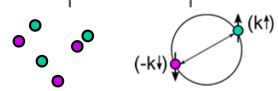

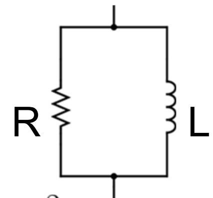

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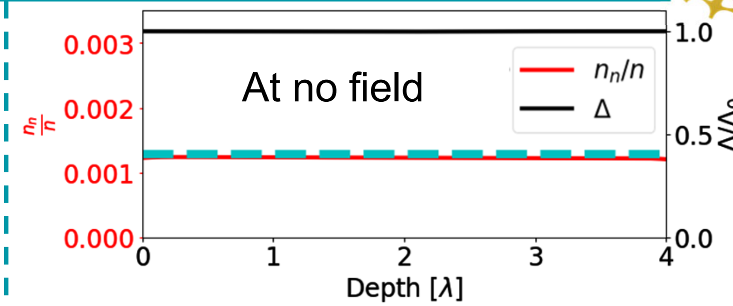

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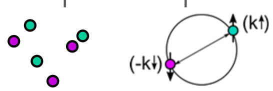
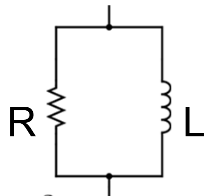
A “three”-fluid model with Bogoliubov quasiparticles

Two-fluid model

$$n_{\text{tot}} = n_n + n_s$$





$$\sigma = \frac{n_n e^2 \tau}{m} + i\frac{n_s e^2}{m\omega}$$

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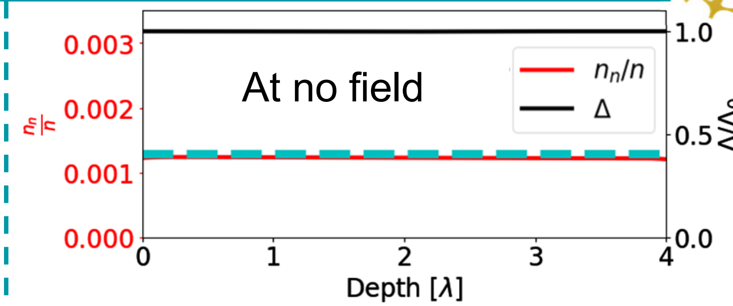

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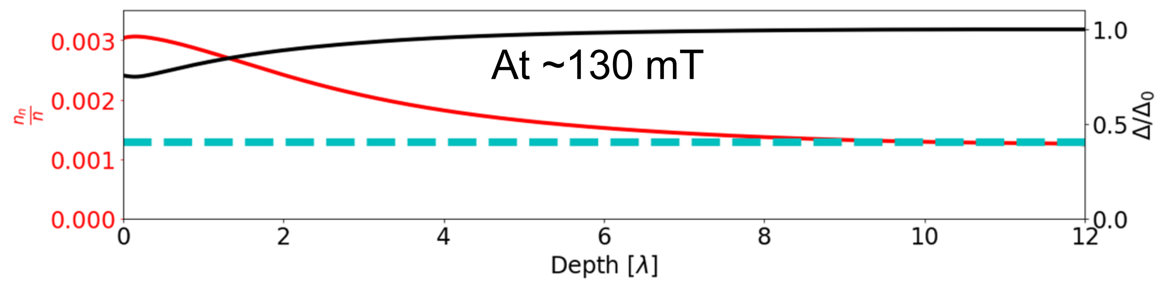

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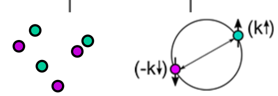

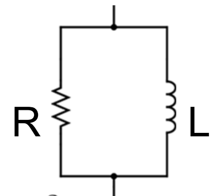

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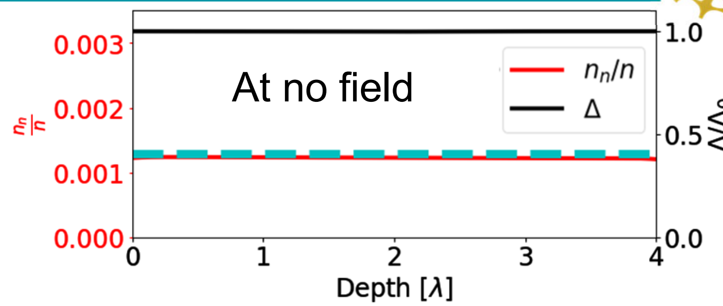

bound or continuum

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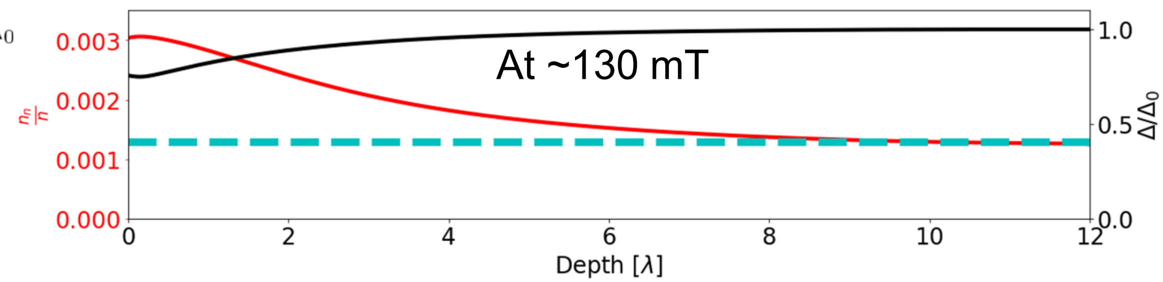

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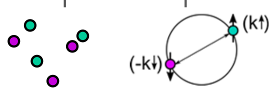

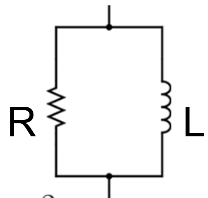

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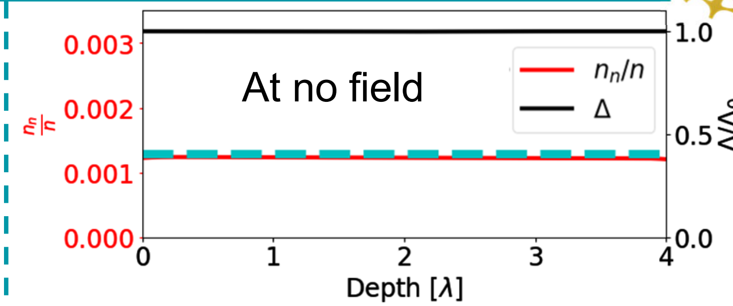

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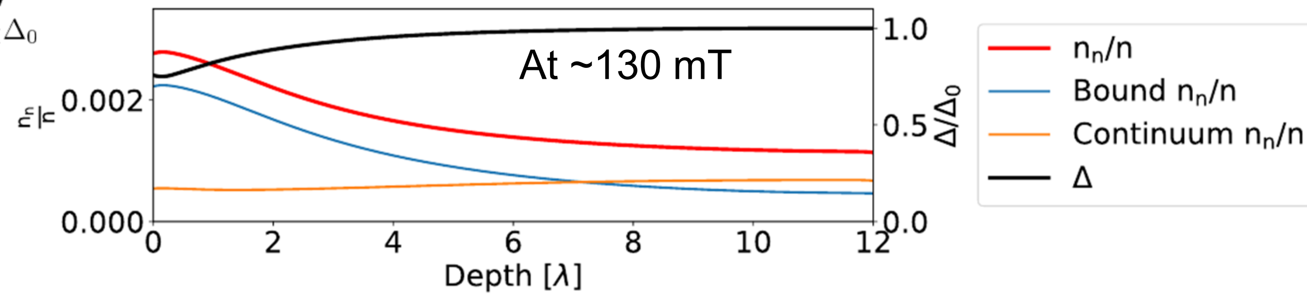

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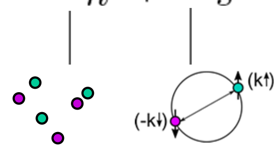

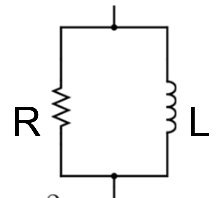

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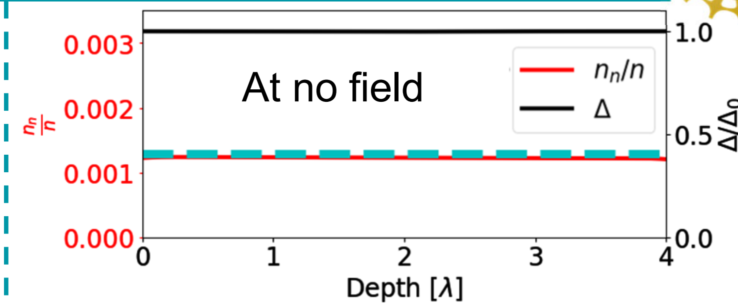

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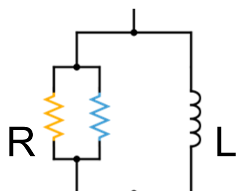

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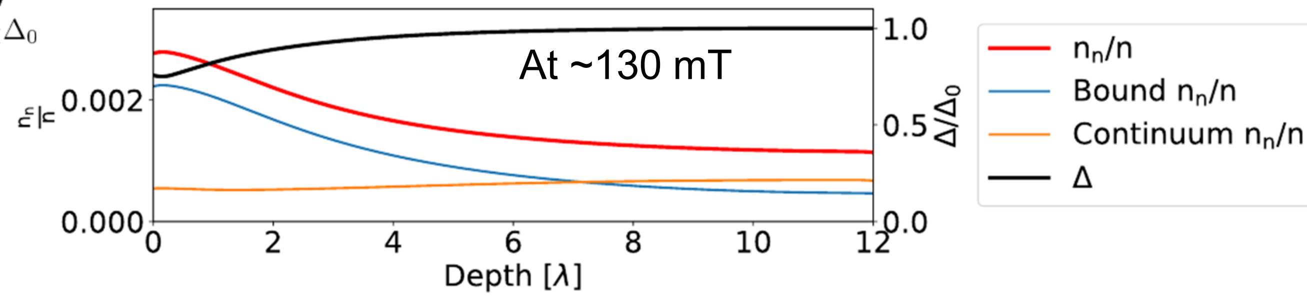

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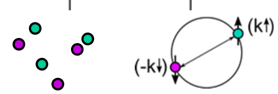

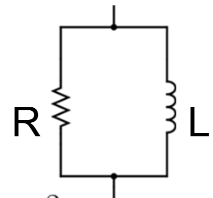

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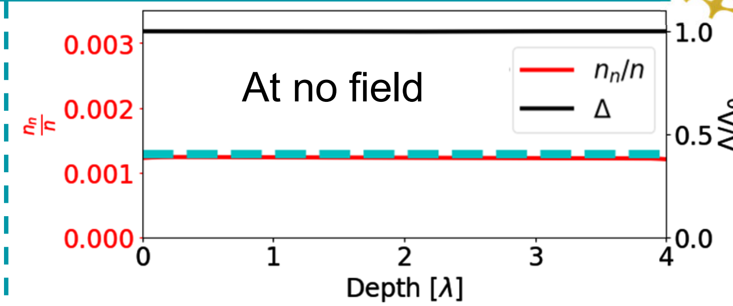

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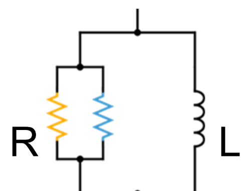

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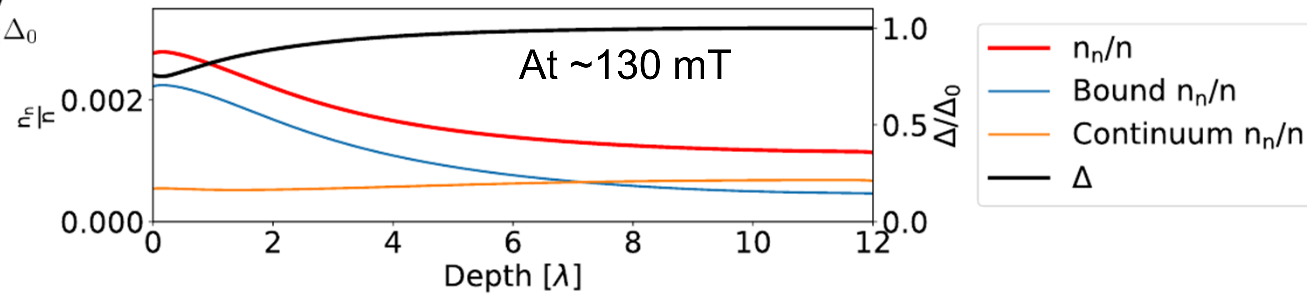

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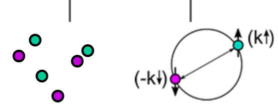

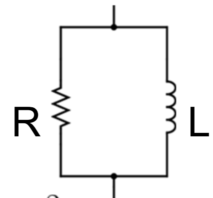

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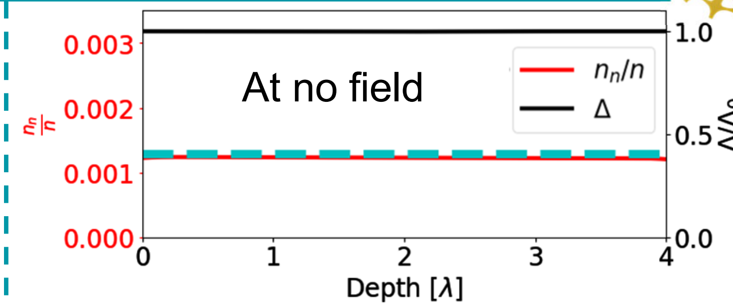

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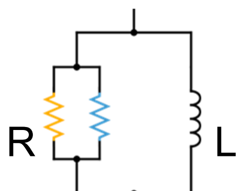

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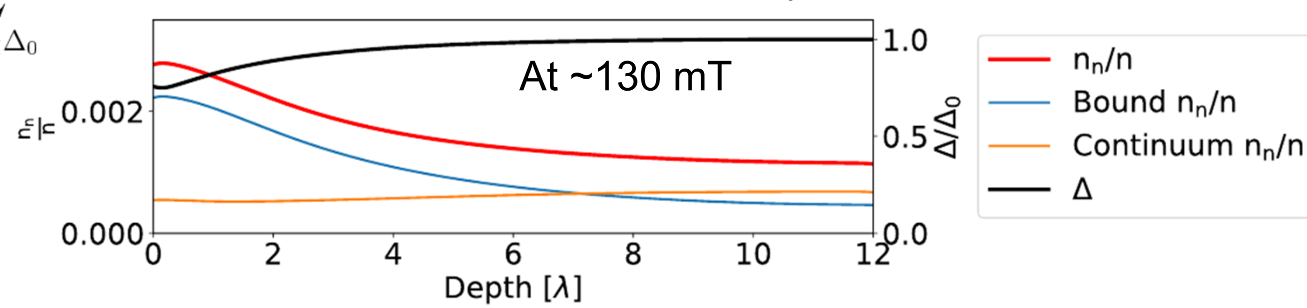

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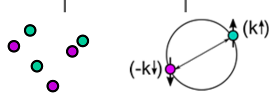

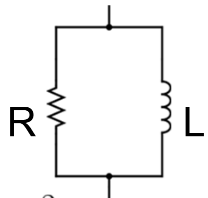

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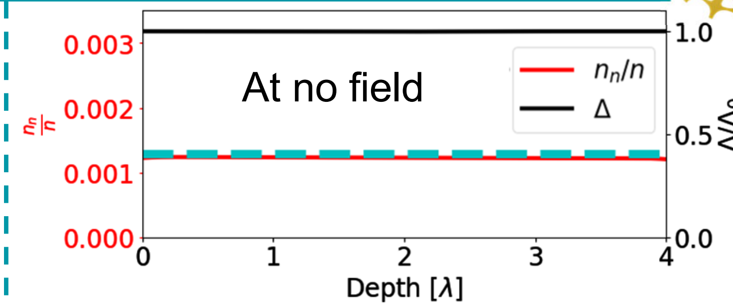

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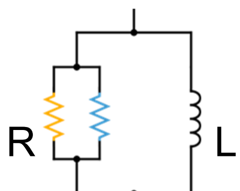

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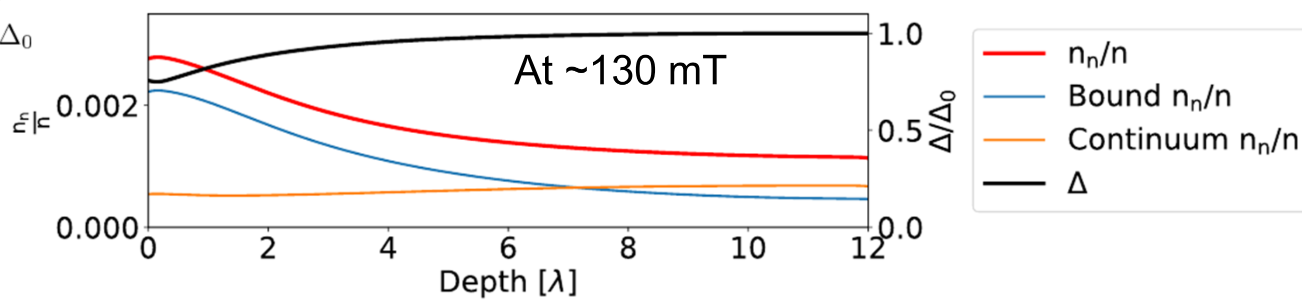

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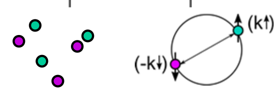

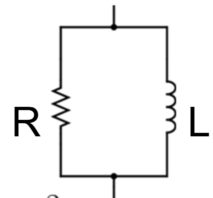

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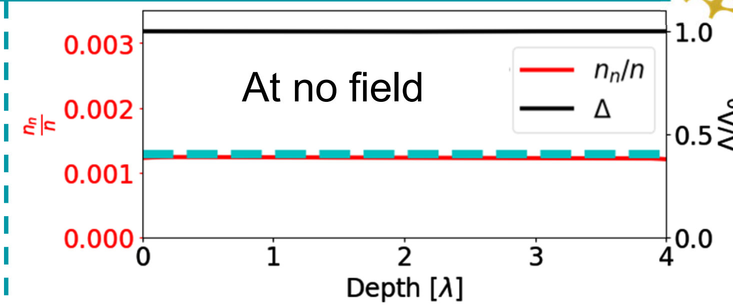

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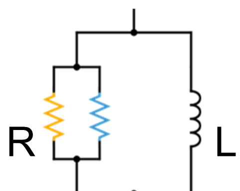

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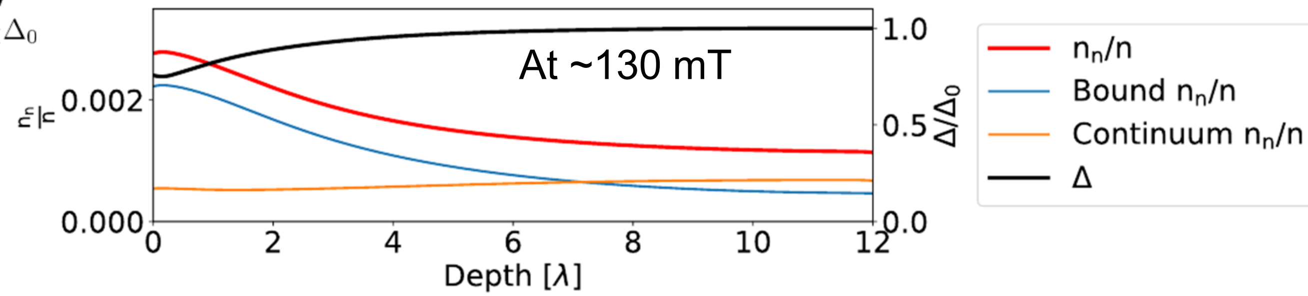

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potential strength (*ab initio*) & impurity concentration

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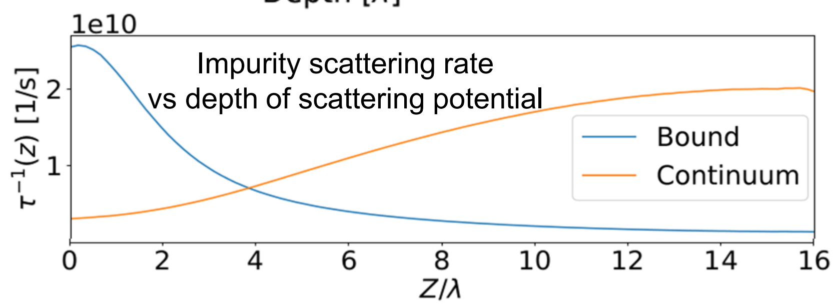

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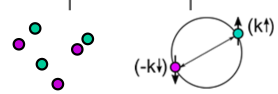

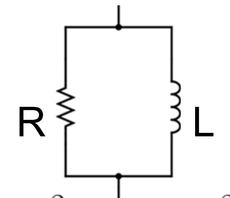

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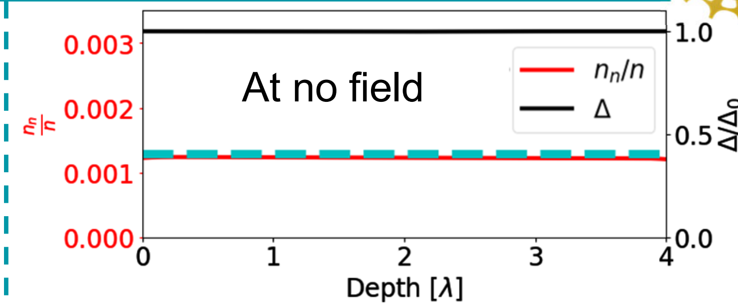

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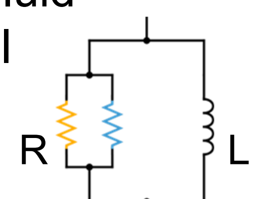
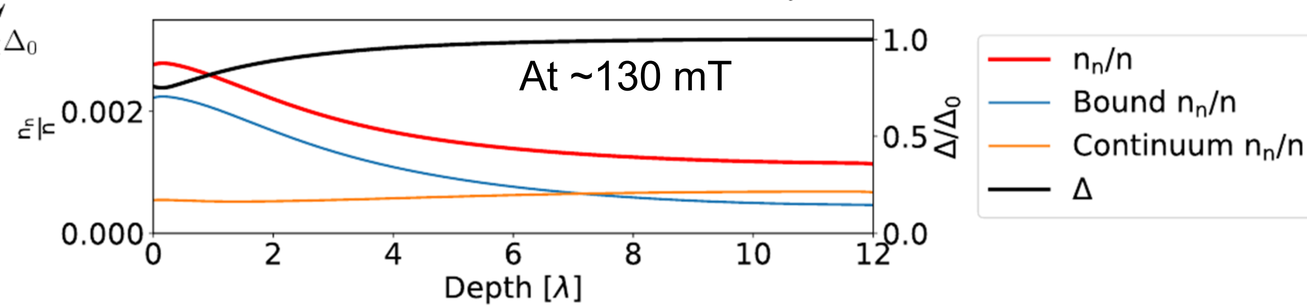


$$\sigma = \frac{e^2(\tau_{\rm b} n_{\rm b} + \tau_{\rm ub} n_{\rm ub})}{m} + i\frac{e^2 n_s}{m\omega}$$

bound $\sum_{i:|E_i|<\Delta_0}$ or continuum $\sum_{i:|E_i|\geq\Delta_0}$

$$\frac{n_n}{n_{\text{tot}}}(z) = \frac{1}{N(0)} \sum_i \left(-\frac{\partial f(E_i)}{\partial E_i}\right) [|u_i(z)|^2 + |v_i(z)|^2]$$

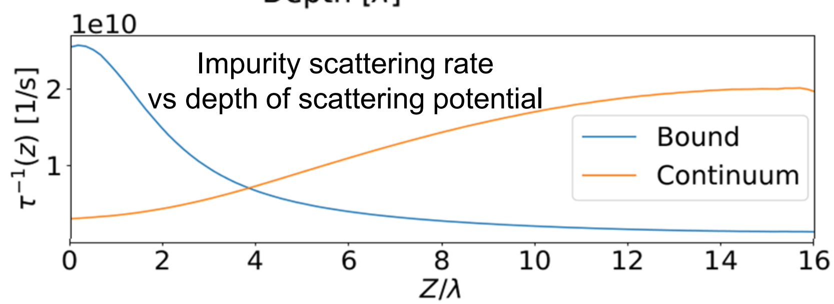


BdG quasiparticle–impurity scattering

$$\tau^{-1}_{n\mathbf{k}_{||}} = \frac{1}{N_{\mathbf{k}_{||}}} \sum_{\mathbf{k}_{||}} \frac{2\pi}{\hbar} \alpha^2 n_{\text{imp}}(z_0)(1 - f_{n'\mathbf{k}'_{||}})\delta(E_{n\mathbf{k}_{||}} - E_{n'\mathbf{k}'_{||}})$$
$$|u_{n\mathbf{k}_{||}}(z_0)u_{n'\mathbf{k}'_{||}}(z_0) + v_{n\mathbf{k}_{||}}(z_0)v_{n'\mathbf{k}'_{||}}(z_0)|^2$$

potential strength (*ab initio*) & impurity concentration

coherence factor



A “dirty” surface can enhance scattering rates of the surface-bound states

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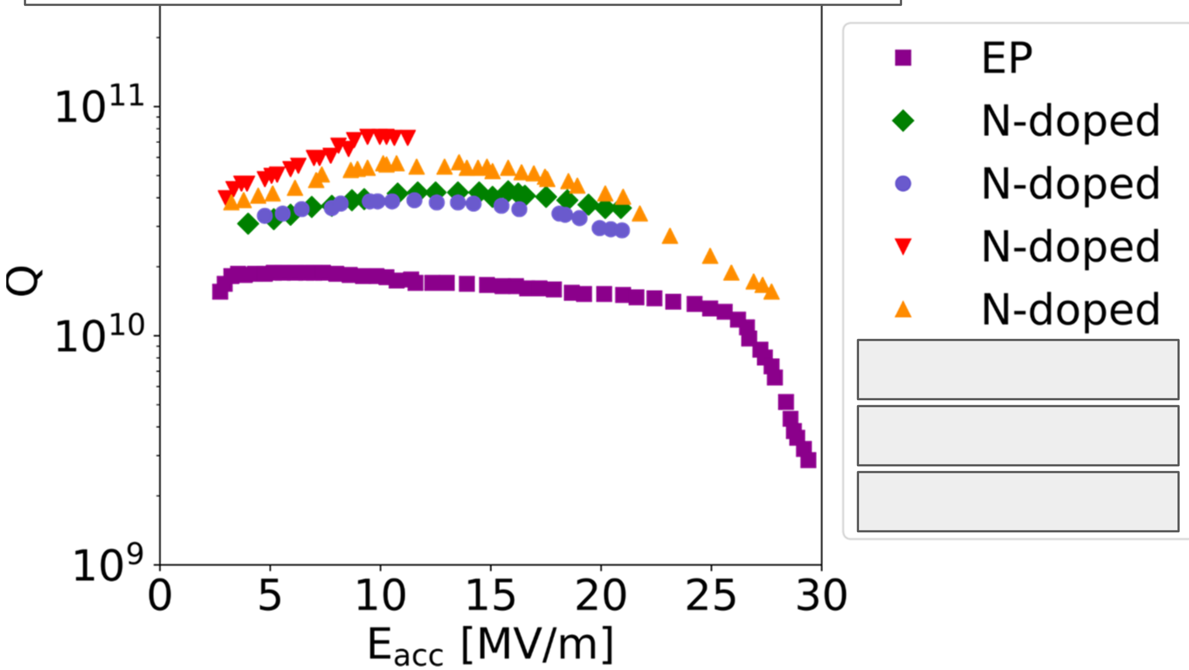

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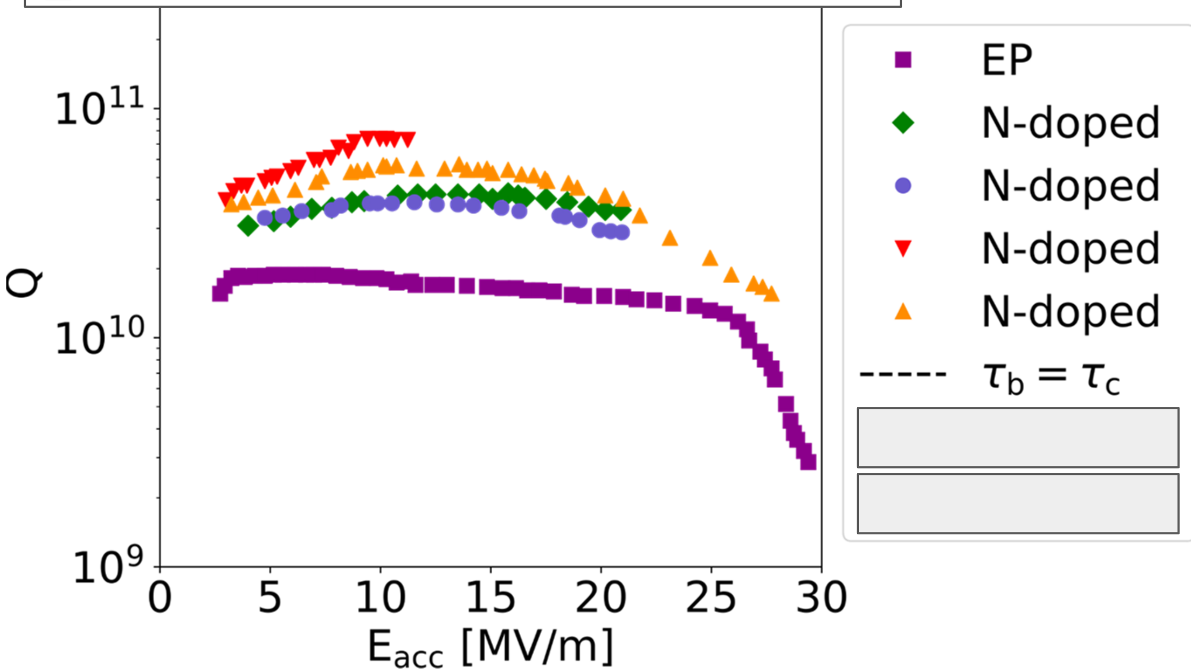

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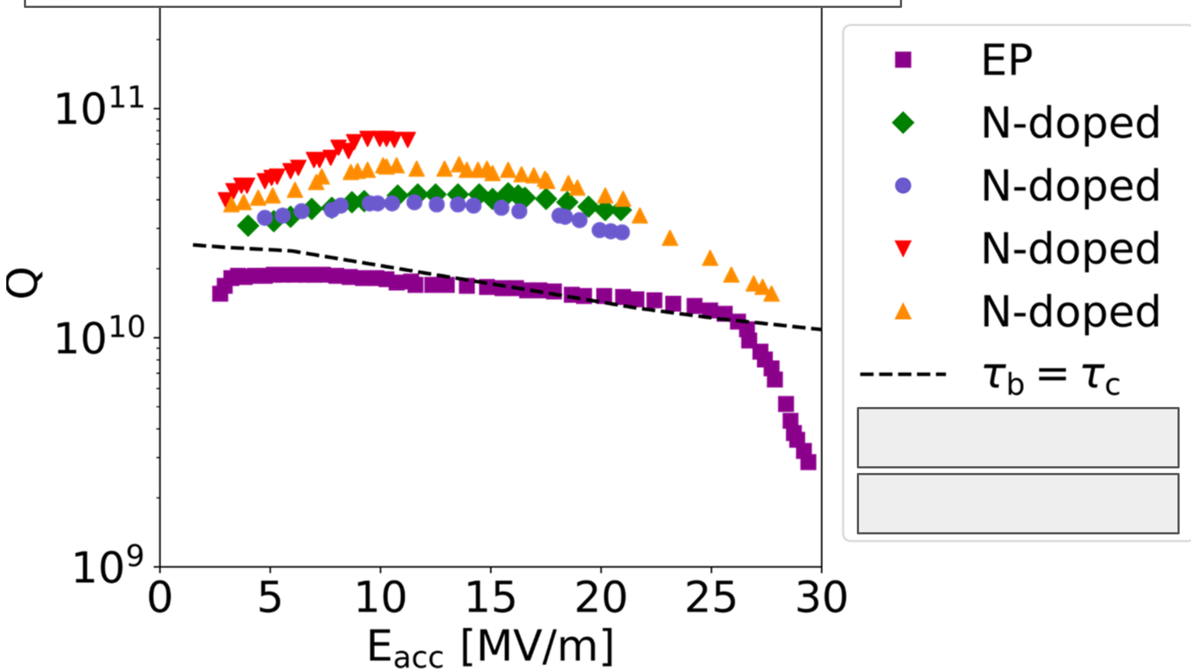

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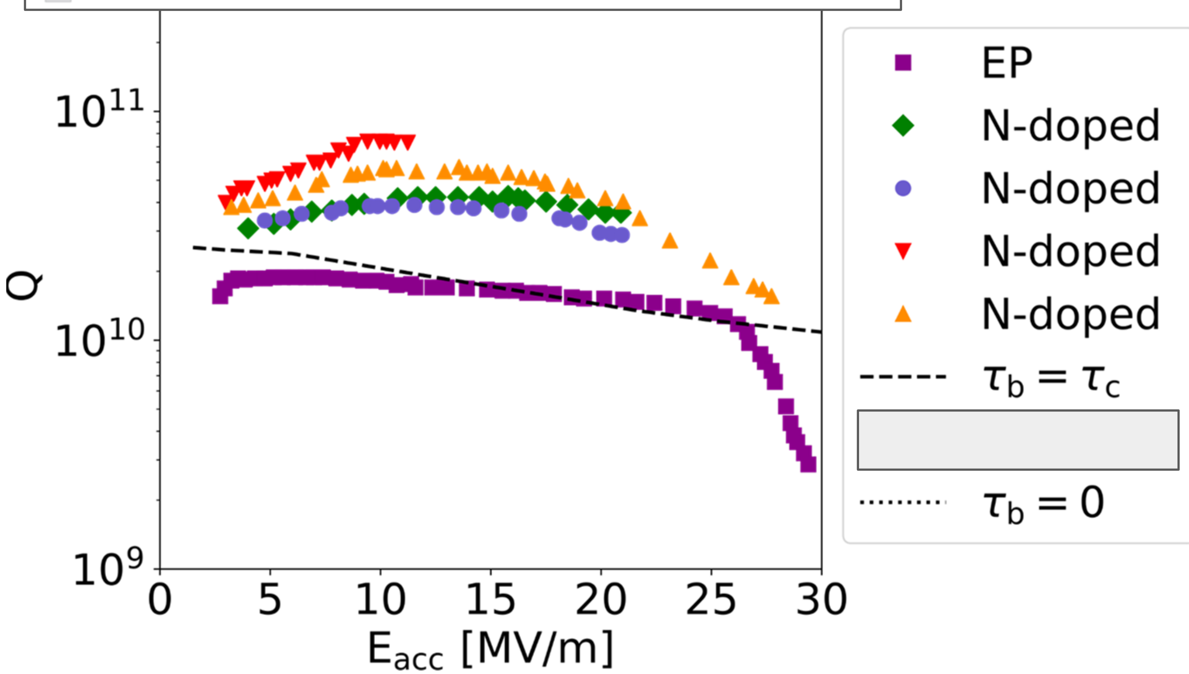

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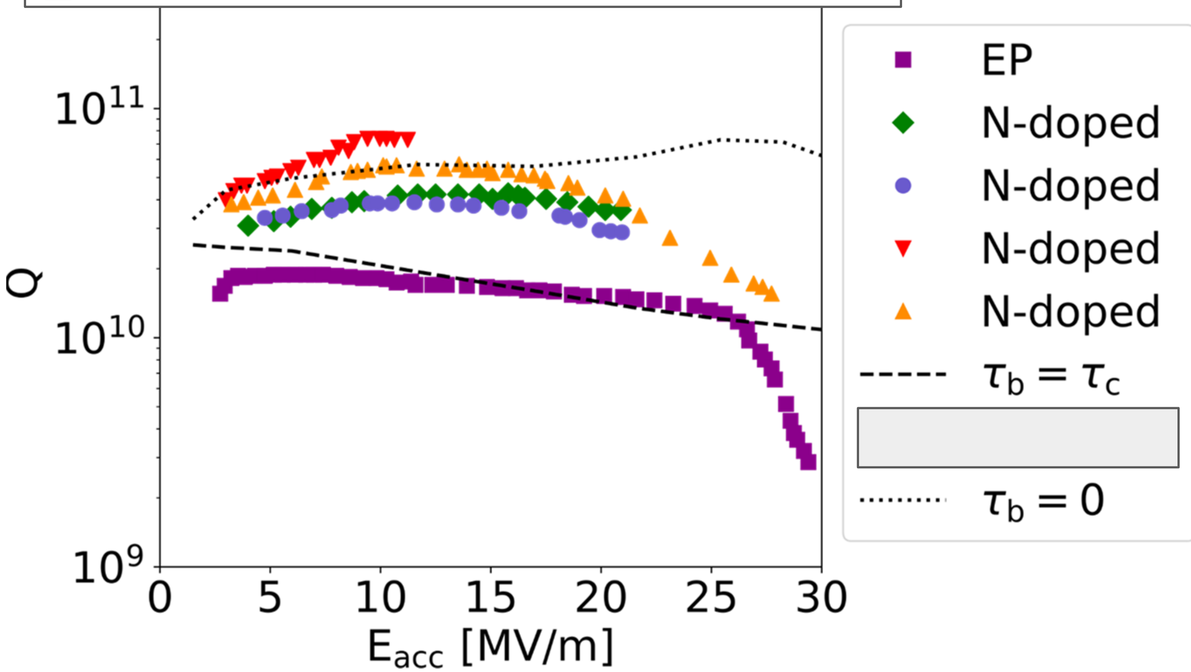

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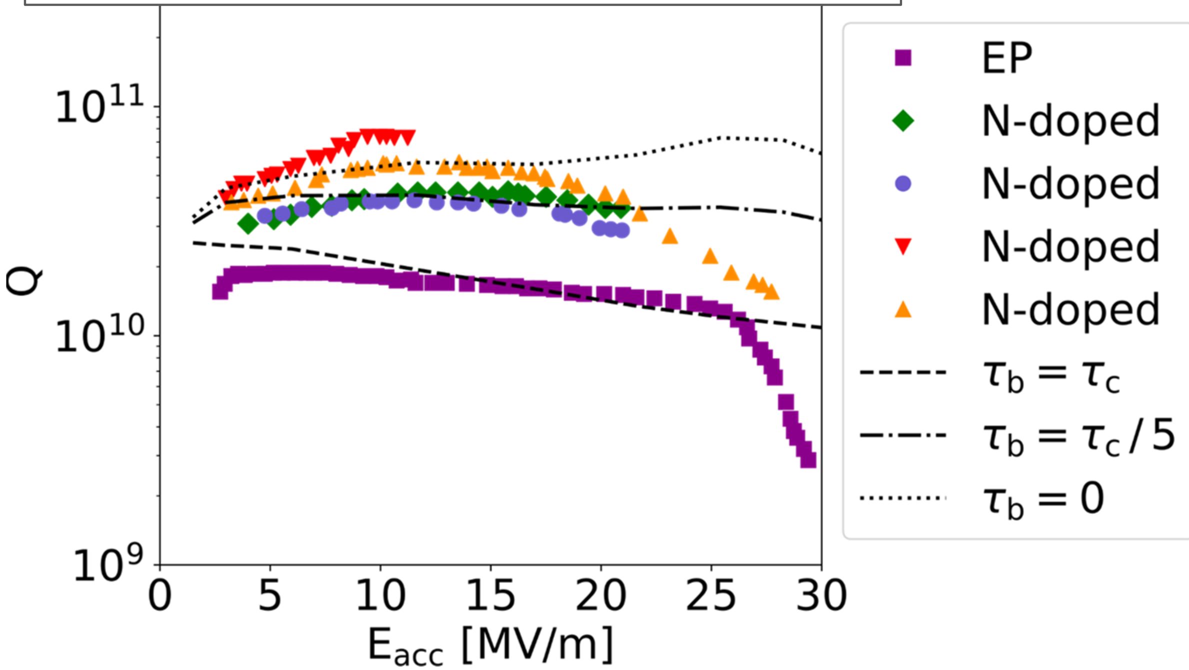

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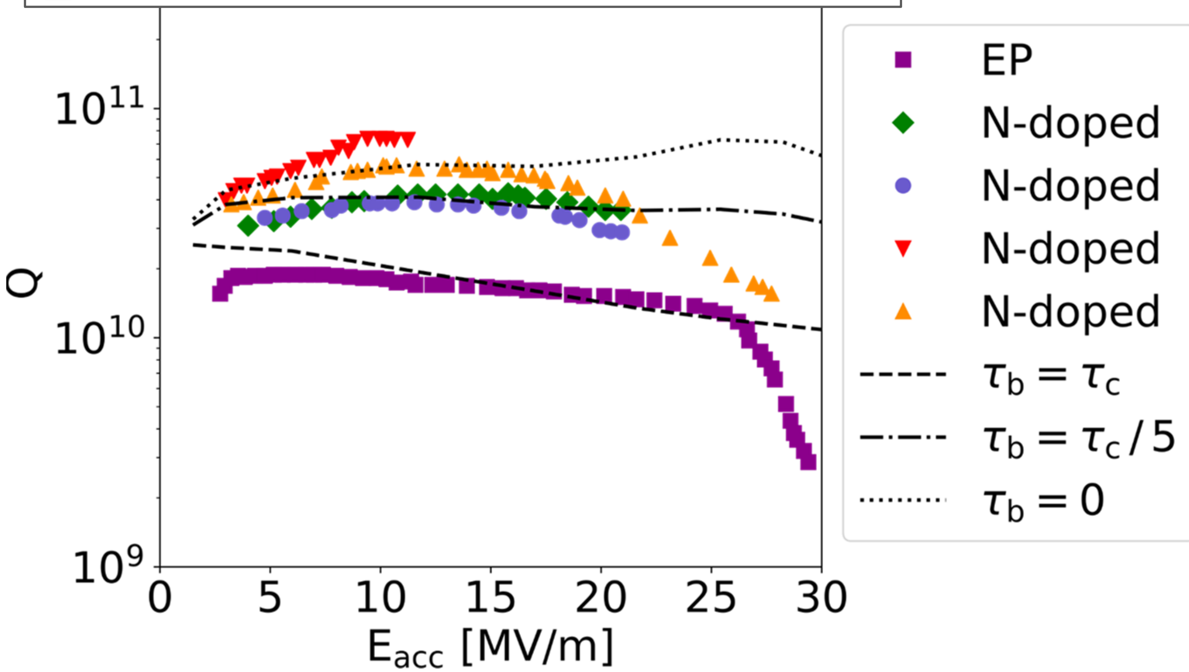

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Questions?

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