



CRITICAL FLUCTUATIONS AS A SOURCE OF EXCESS NOISE IN A TES IN A **CORBINO DISK GEOMETRY**

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Outline



- Introduction
- Critical fluctuations of the order parameter (*Ginzburg-Landau –approach*)
 - Essentially the Nagaev theory in GL limit
- The (Orso Maria) Corbino disk TES
- Excess noise in the Corbino TES
- Generalization to other geometries
- Conclusions

Noise sources



- **Phonon noise (thermal fluctuation noise):**
 - Spontaneous fluctuations of energy across the thermal link
- **Johnson noise**
- **SQUID noise**
- **Internal TFN**
- **These noise sources can be modeled accurately**

- **Theoretical resolution**

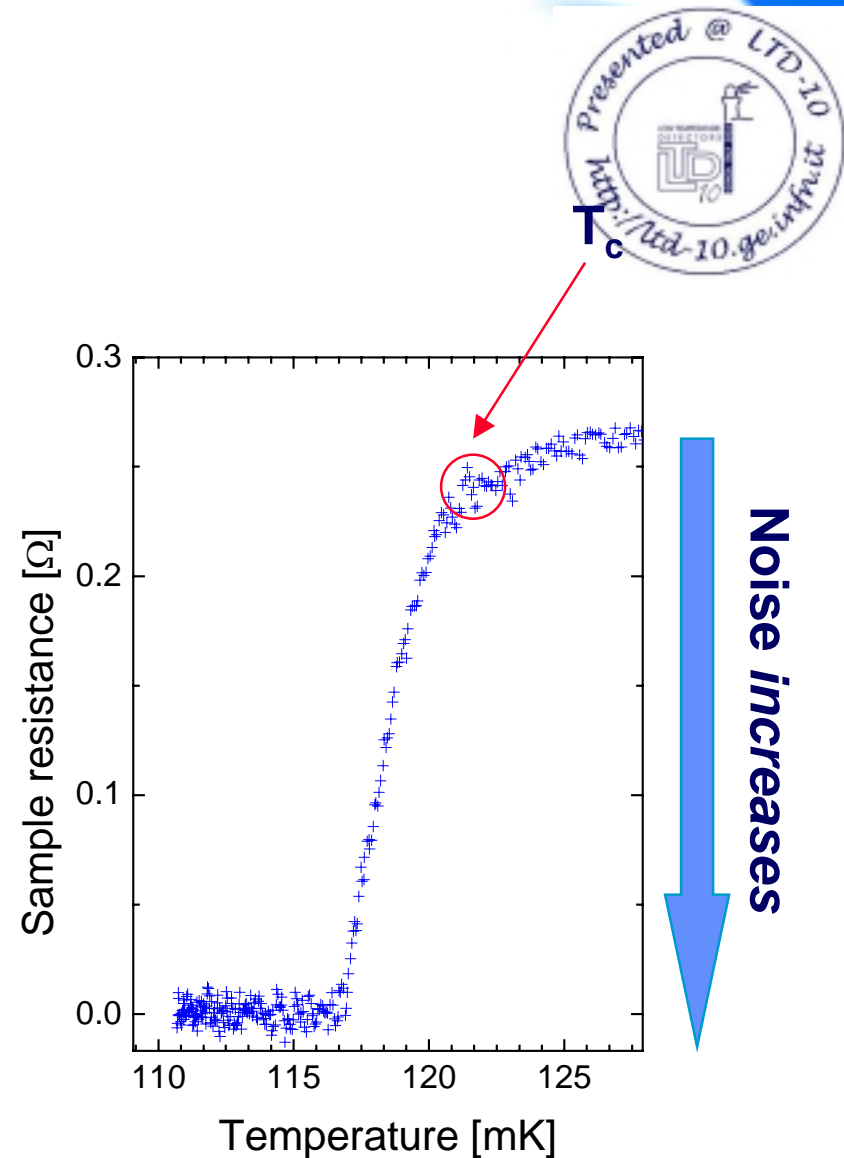
$$\Delta E_{FWHM} = 2.36\eta\sqrt{k_B T_c^2 C}$$

$$\eta = \left[\gamma \left(\frac{1}{\alpha L} + \frac{G}{G_{TES}} \right) + \left(\frac{1}{\alpha L} + \frac{G}{G_{TES}} \right)^2 \right]^{1/4}$$

- **$\eta \sim 0.1$ predicted \rightarrow resolution in the 1 eV range...**

Excess noise

- However, *no-one* has demonstrated $\eta < 0.5$
- \rightarrow something is missing from the model
- First reports of excess noise already in 1969! (Maul et al.)
- Most groups see excess noise when biased low in transition
- Combined with requirements for τ , dynamic range \rightarrow we have a problem

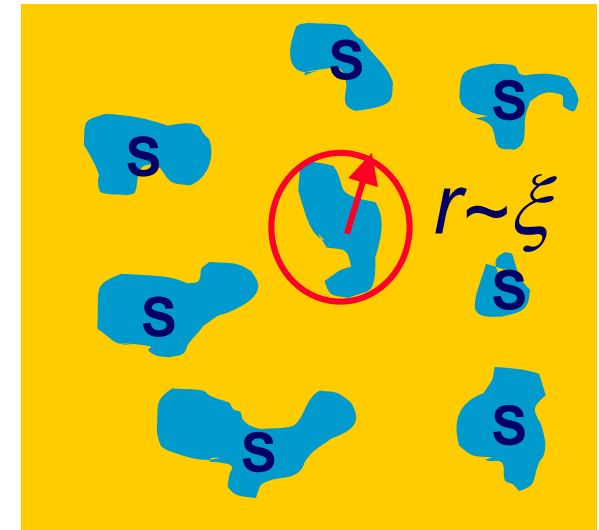


Critical fluctuations in superconductors near T_c : Superconductivity *above* T_c



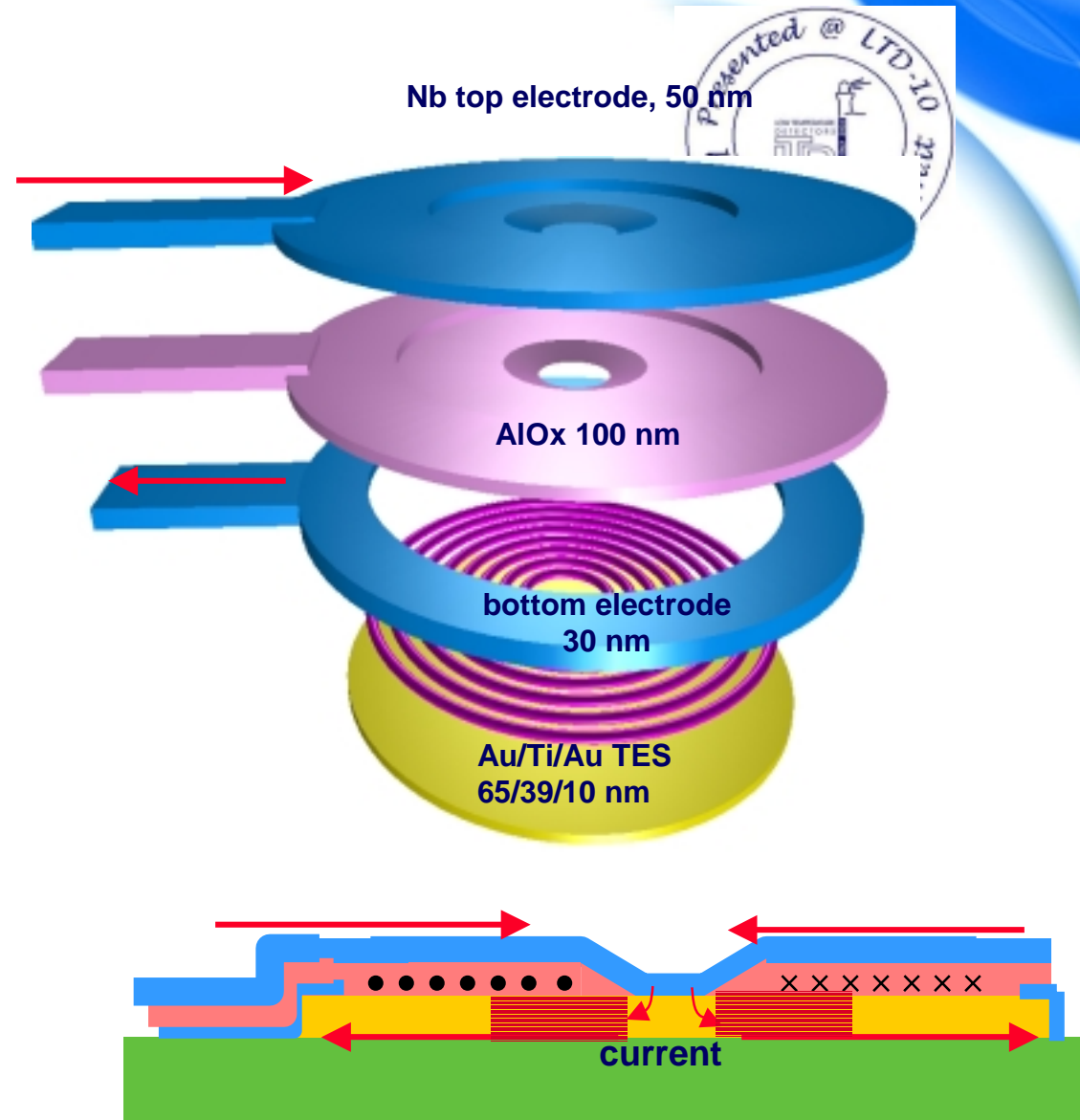
- Superconducting phase described by the complex order parameter $\psi(r) = |\psi(r)|e^{i\phi(r)}$
- Free energy associated with the condensate $F = (\alpha|\psi|^2 + \frac{1}{2}\beta|\psi|^4)\Omega$ ($H=0, \nabla\psi=0$)
- In small samples or at temperatures very close to the T_c , fluctuations in the *free energy* $\delta F \sim k_B T_c$ are significant
- Aslamasov-Larkin theory of fluctuation superconductivity above T_c + experiments
- 'Droplets' of s.c. with a characteristic size $r \sim \xi(T) \propto |1 - T_c/T|^{1/2}$
- At DC, conductivity increase in 2d films by

$$\sigma_{AL} = \frac{e^2}{16\hbar d} \frac{T}{T - T_c}$$

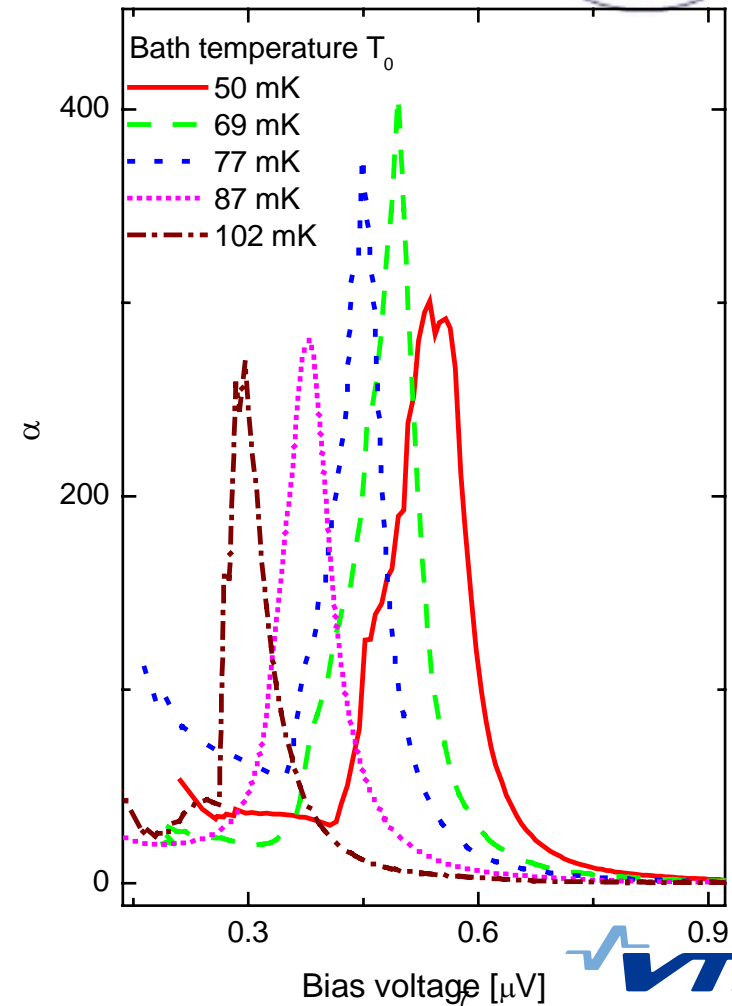
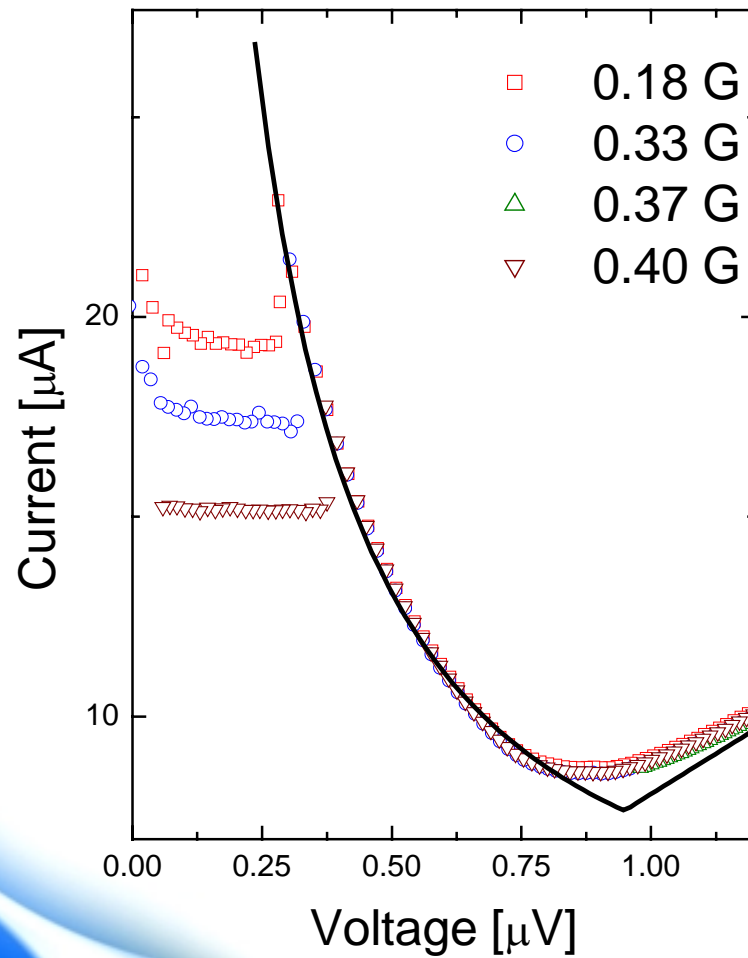


Corbino disk TES

- Diagnostic tool: Corbino geometry TES (CORTES)
- $J(r)$ determined by the geometry
- no edge effects
- $T(r)$ can be modeled analytically:
 - diffusion problem
 - $\kappa_{\text{TES}} \gg \kappa_{\text{SiN}}$: neglect membrane
- Azimuthal magn. field, expelled from the s.c.
- phase separation

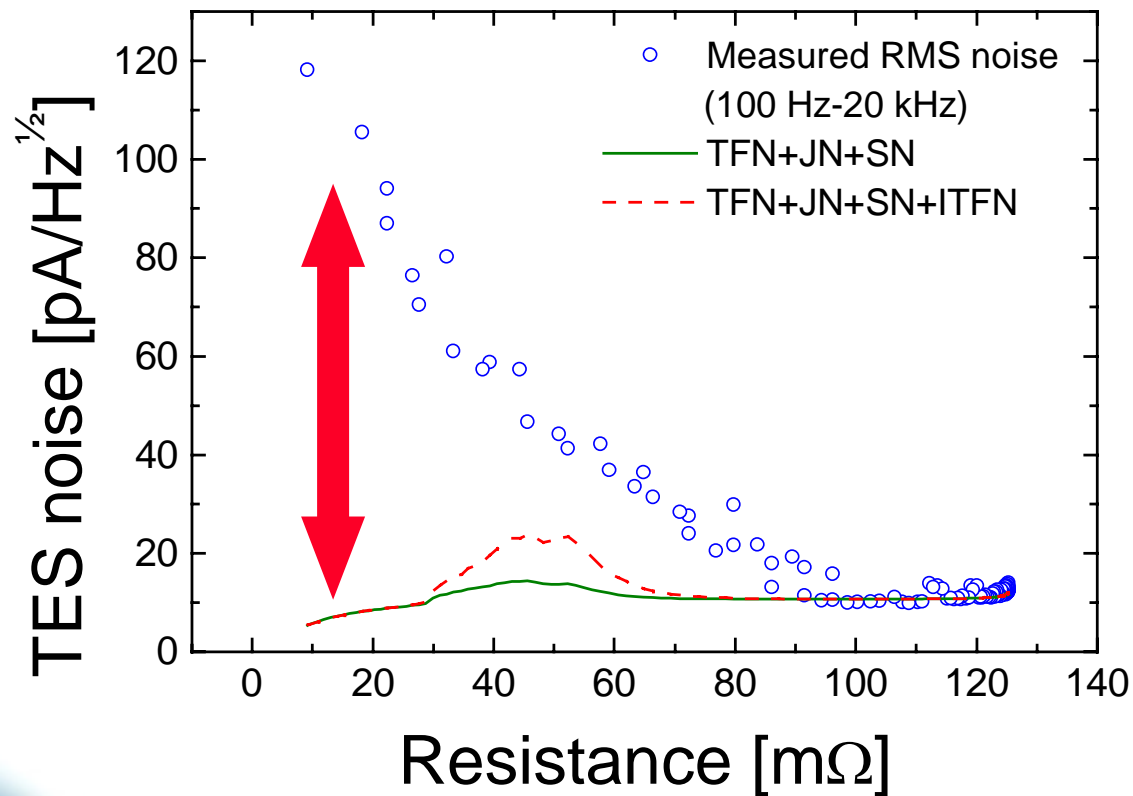


CorTES I-V Curve



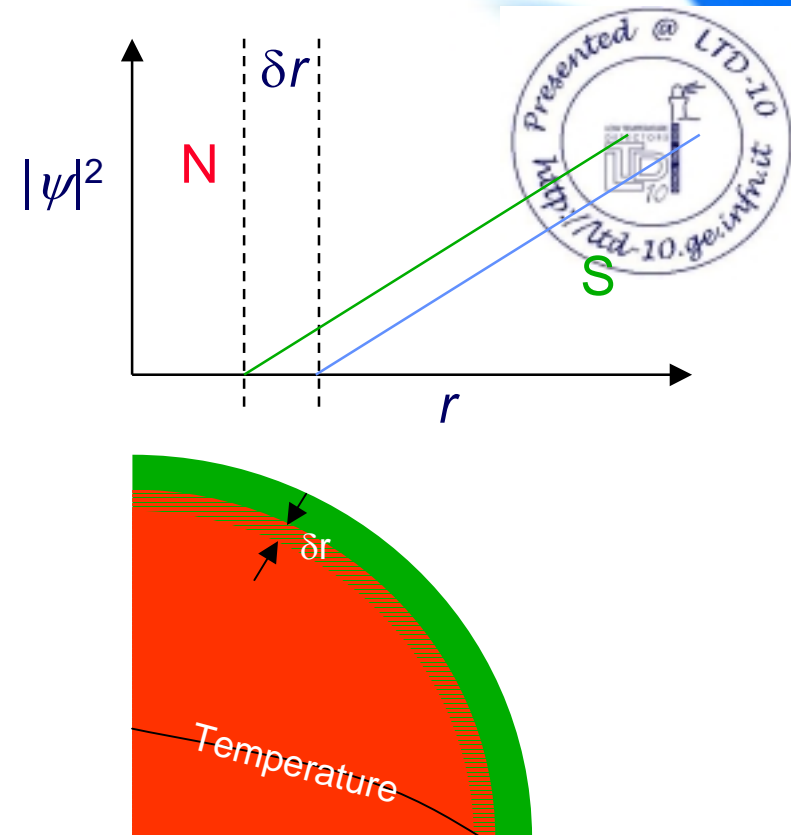
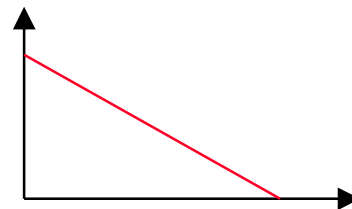
Excess noise

- **HUGE** excess noise!



Excess noise

- Thermal fluctuation of the free energy (not *temperature* fluctuation!)
- At the N-S boundary $\xi \rightarrow \infty \rightarrow$ fluc_s. correlated
- Near T_c , $|\psi|^2 \propto (1 - T/T_c)$
- 0th mode fluctuation – displacement of the S-N boundary δr
- Identify a fluctuating volume with a fluctuation in the G-L free energy $k_B T_c \sim 9 \mu\text{eV}$
- $T/T_c - 1 \sim k\delta r$



$$\delta F \cong k_B T_c \cong -\frac{\langle \alpha_{GL}^2 \rangle}{2\beta_{GL}} \delta\Omega,$$

$$\delta\Omega = 2\pi r_b \delta r t$$

Excess noise

- Temperature gradient k calculated from diffusion eq. using W-F law for heat transport

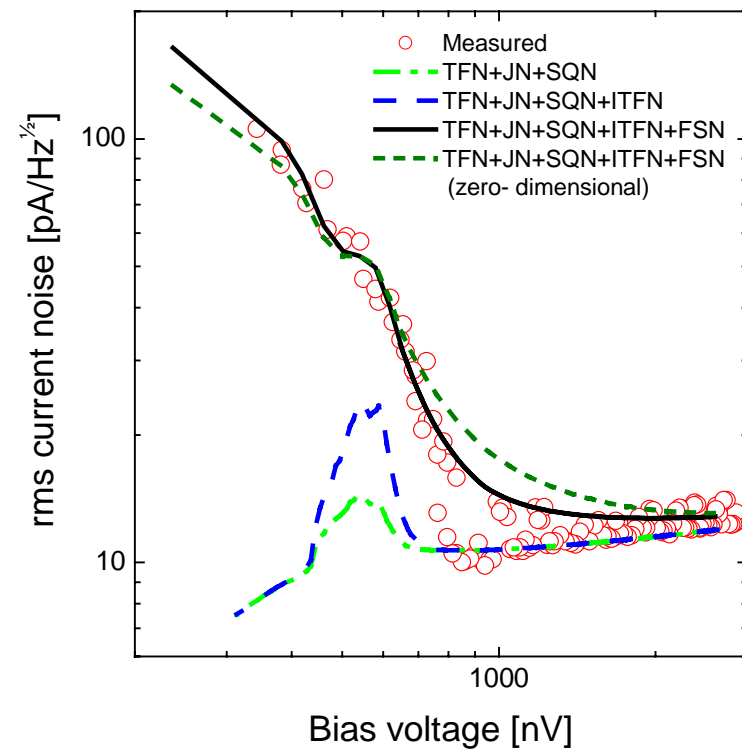
- Lifetime of flucTs from time-dependent G-L theory: $\tau_{GL} = \frac{\pi\hbar}{8k_B(T - T_c)}$

- Assumed white until $1/\tau_{GL}$

- Solution for $\delta r \rightarrow \delta R \rightarrow \delta I$

- Good fit with one free parameter, Lorentz number $L = \text{const} \times L_{N0}$

- Zero-D limit: Ω associated with the *entire volume*



Excess noise

- Also noise spectra can be modeled accurately
- Current noise given by

$$\delta I_{fsn} = \frac{0.24IT_c L}{V^2} \frac{1 + \beta}{2(1 + \beta L_0)} \Gamma \frac{\sqrt{1 + \omega^2 \tau_0^2}}{\sqrt{1 + \omega^2 \tau_e^2}}$$

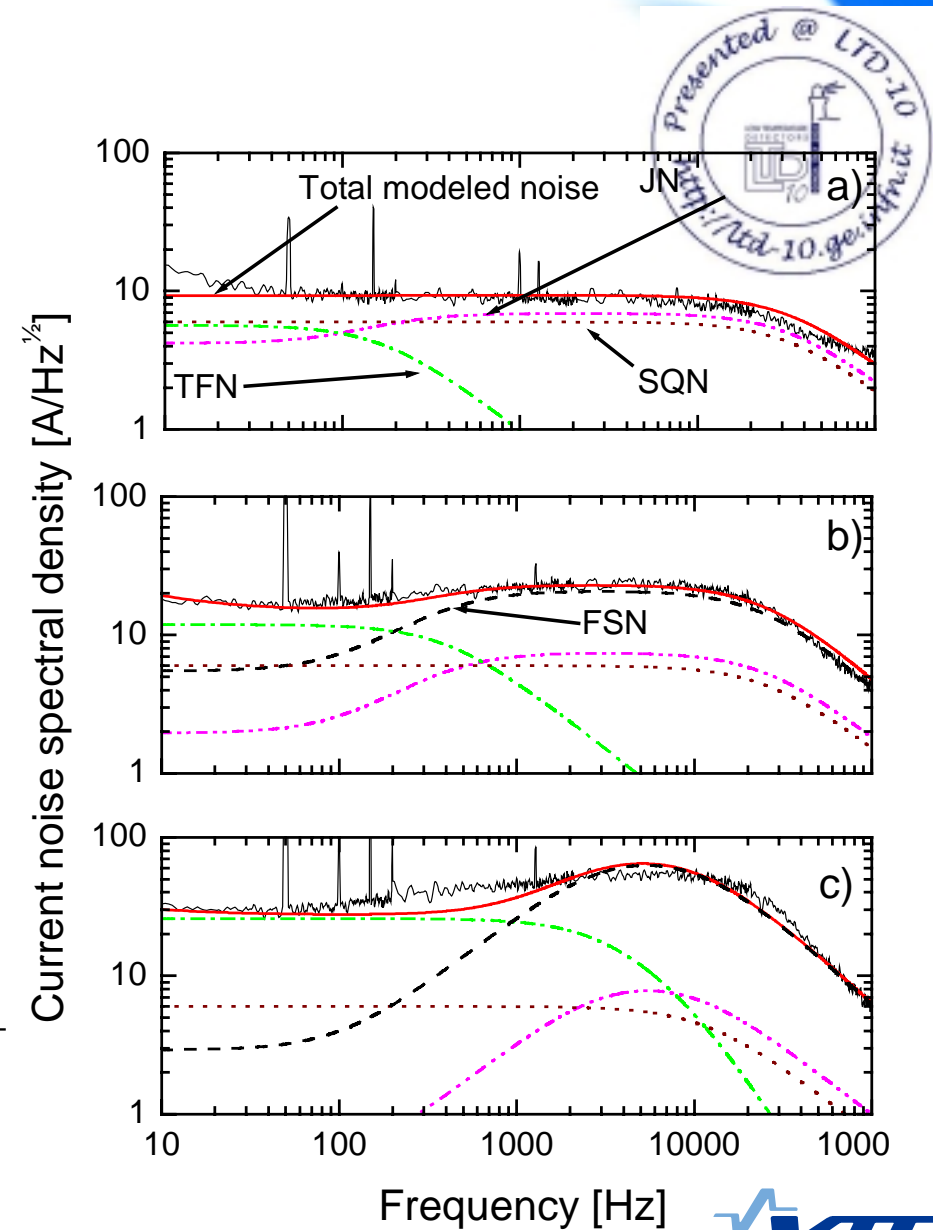
where

$$\Gamma = \left[\frac{\hbar T_c^2 k}{\pi N(0) k_B^4 d r_i (1 + 2\pi R d \rho_N^{-1})} \right]^{1/6}$$

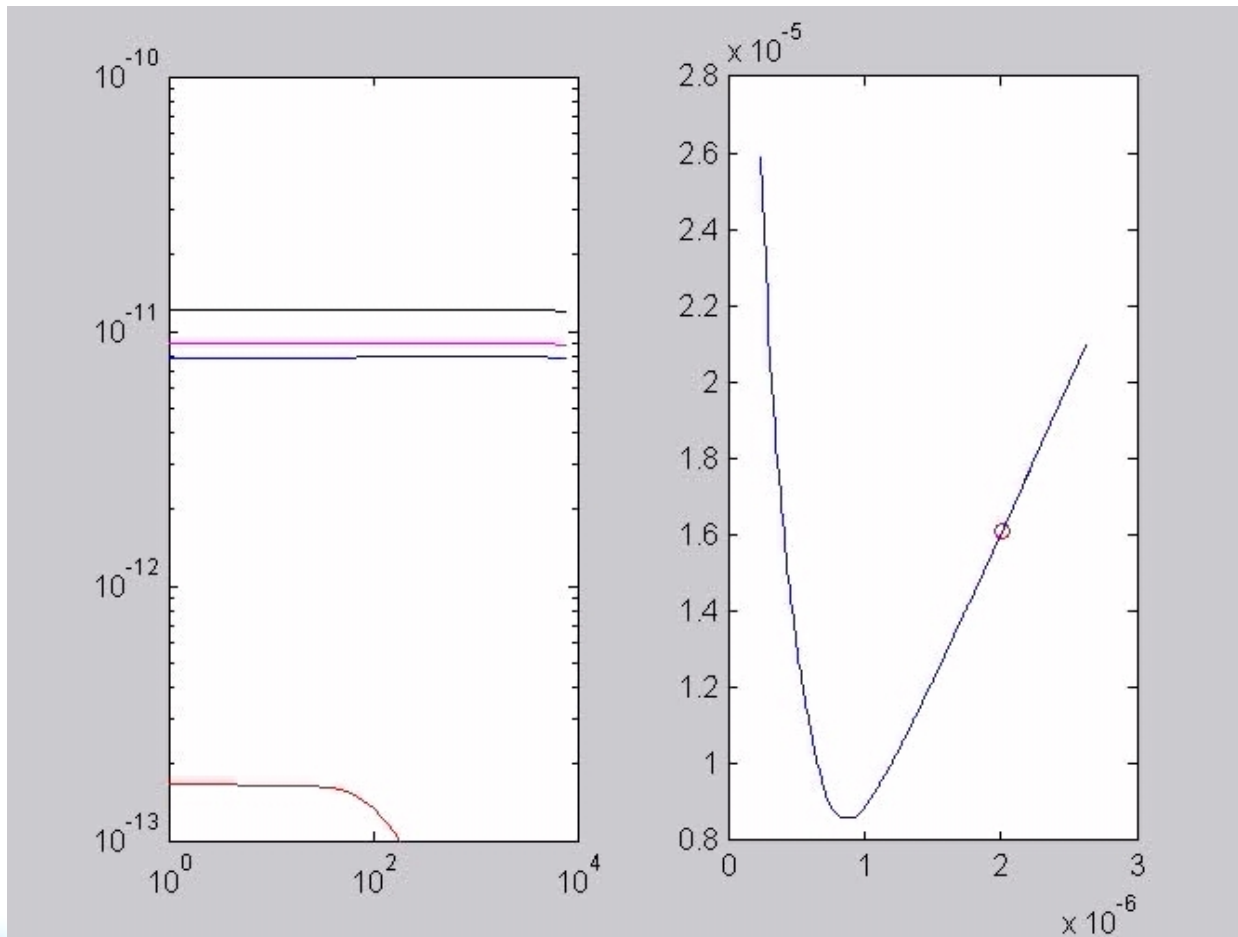
With perfect V-bias, $L_0 \gg 1$:

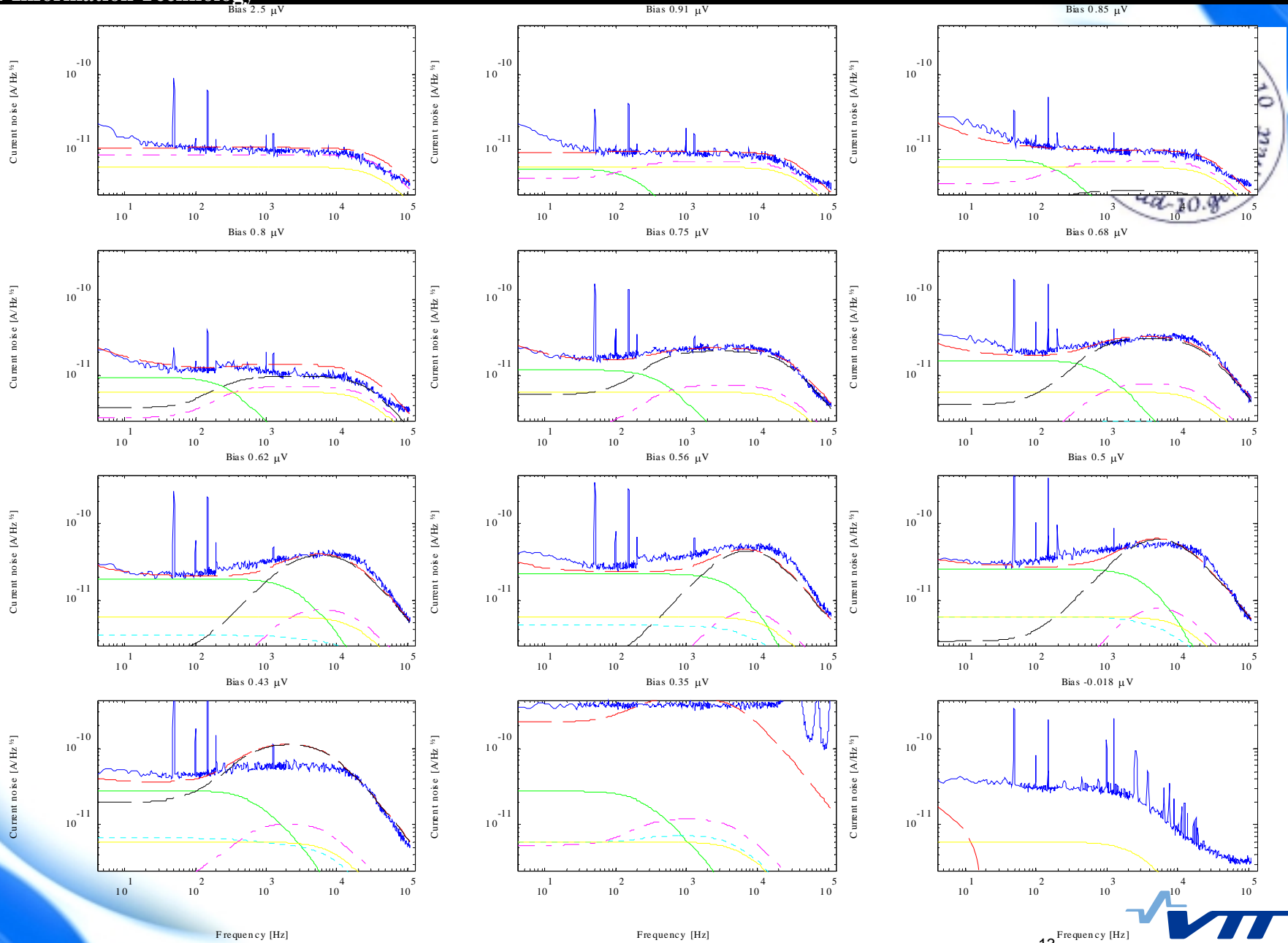
$$\delta I_{fsn} \propto \frac{I}{V^2 L_0} \frac{1}{(1 + 2\pi R d \rho_N^{-1})^{1/3}}$$

$$\approx \frac{I}{V^2 L_0}$$



Excess noise: the movie





Excess noise: Implications



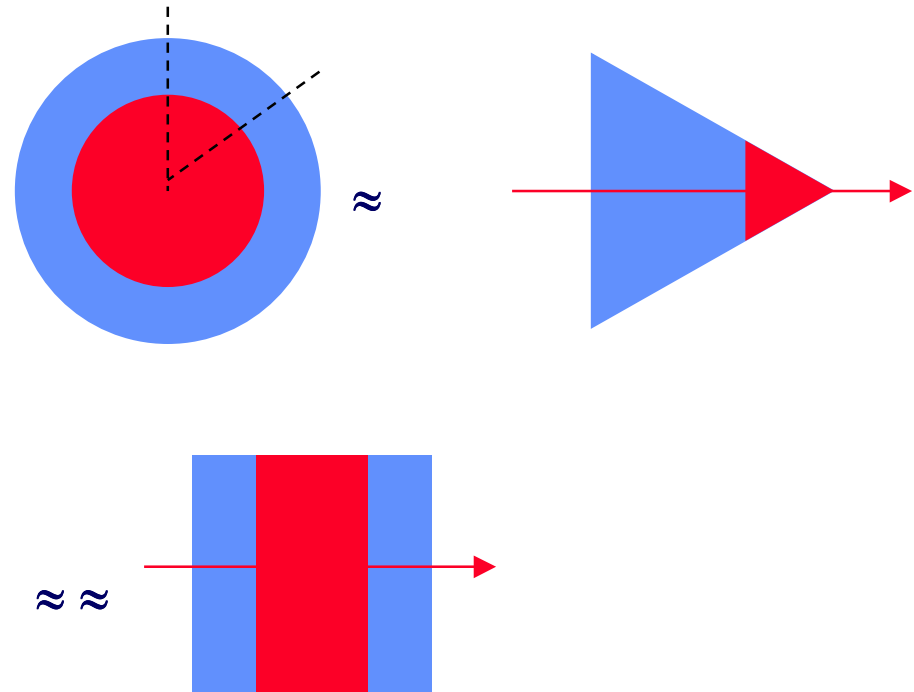
- A fundamental noise source in transition-edge sensors
- Contribution to Noise equivalent power

$$NEP \approx \frac{0.24LT_c^2G}{V^2\alpha} \sqrt{1 + \omega^2\tau_0^2}$$

Excess noise: extrapolation to squares?



- Assuming no flux flow resistivity can be applied to squares
- Temperature gradient?
- Phase separation in other geometries, too as suggested by the transition width
- Current distribution?
- Functional behaviour as in CorTES case
- A comparison with experiments required

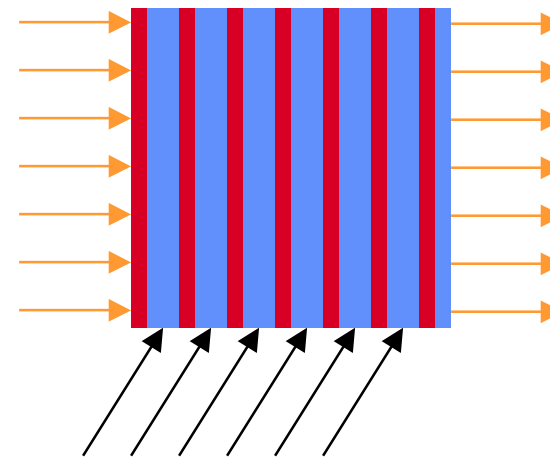




Excess noise: Implications

- **Possible remedies**
 - Break the correlation - bias several TES in parallel/series?
 - With CORTES parameters , $n > 100$ segments required!
 - Split to several independent TESs
 - Use of magnetic field to reduce ξ : pair-pair corr. function of fluctuations. $\propto e^{-H}$
 - Dope TES with magnetic impurities?
 - Increase R?

$$n = \left(\frac{0.36 T_c L_0 \Gamma}{R \text{NEP}_{TFN}} \right)^3$$



Independent TESs



Conclusions

- **Fluctuation superconductivity noise (FSN) a fundamental noise source in TESs**
 - See, e.g. A. Luukanen *et. al. Phys. Rev. Lett. 90, 238306 (2003)*
- **Modeled accurately in the annular geometry. Our model can be extended to rectangular devices with some brave assumptions. Need experimental verification.**
- **Optimization possible. Can be reduced by**
 - Allowing for longer time constant (smaller bias current)
 - Increase R, but then internal thermal fluctuations arise
 - Couple several TESs in parallel/series
 - Increase volume
 - *Use external magnetic field, dope with magnetic impurities*
 - Flatten temperature gradient (bars)
 - Operate in the kinetic inductance mode further away from T_c
- $\delta I_{\text{FSN}}(H)$ measurement would be great!