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The effect of quasiparticle self-generation on the performance of small gap multiple tunnelling STJs



STJs as photon detectors

Current trend:

- a. small gap (better resolution)
- b. high responsivity (thin homogeneous barriers, low losses)

Modelling:

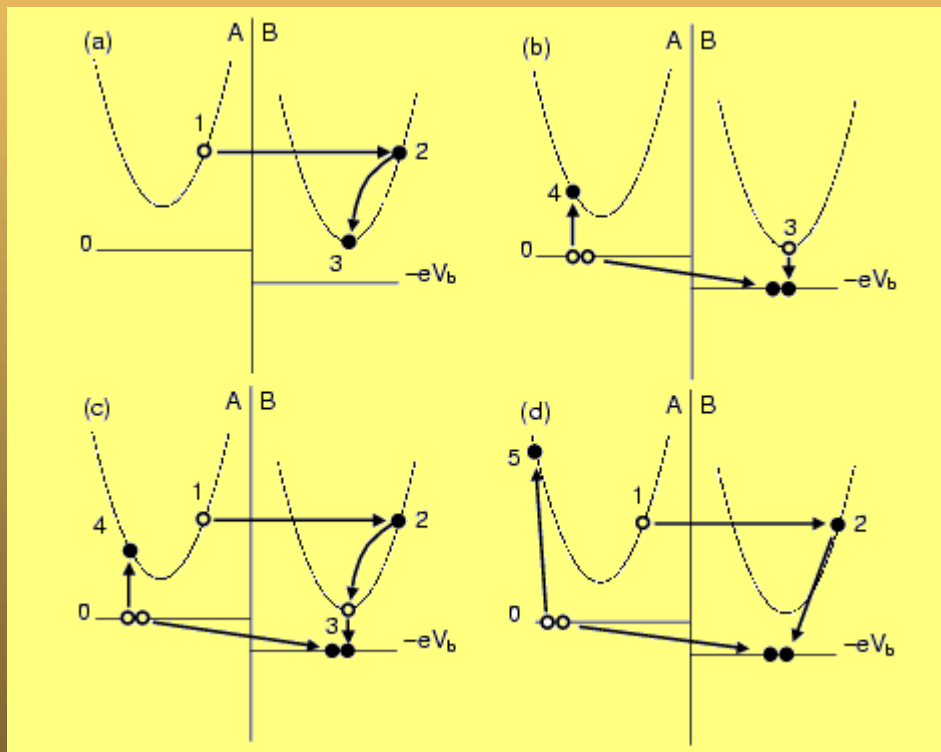
Rothwarf-Taylor scheme (RT-model)

Statement:

For thin barriers with $\rho < 10 \mu\Omega \cdot cm^2$

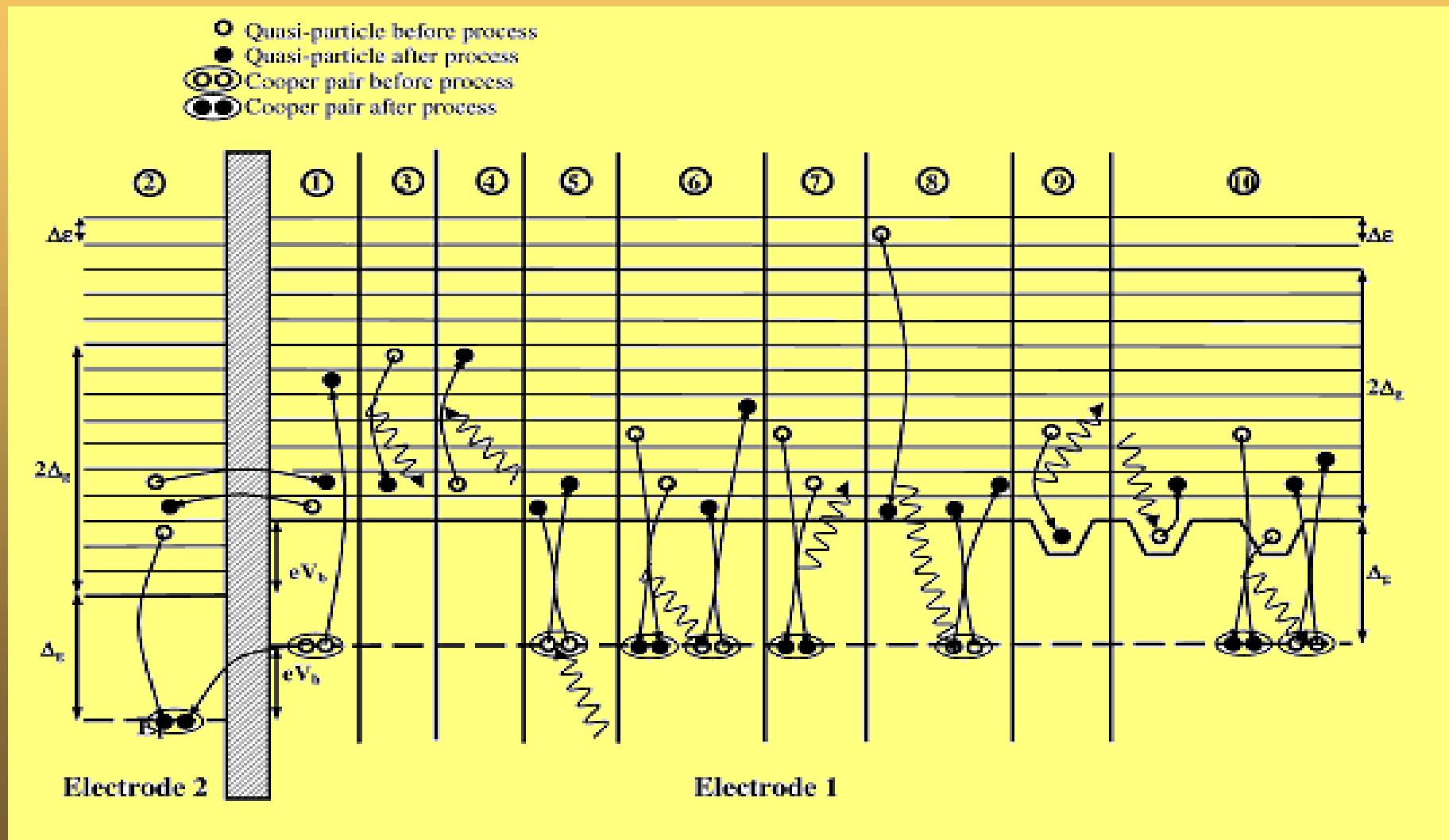
RT model is completely inadequate for the analysis of quasiparticle and phonon dynamics for all traditional superconductors except for unproximised Nb

Energy gain in sequential cycles of direct- and back-tunnelling events



- a. Direct tunnelling $1 \rightarrow 2$,
followed by relaxation $2 \rightarrow 3$
- b. Back-tunnelling $3 \rightarrow 4$
from relaxed state 3
- c. Sequential direct- back-
tunnelling cycle $1 \rightarrow 2 \rightarrow 3 \rightarrow 4$
with intermediate relaxation
- d. Sequential direct- back-
tunnelling cycle $1 \rightarrow 2 \rightarrow 5$ without relaxation

Tunnelling and electron-phonon interaction processes in the STJ





Spectral balance equations

$$\begin{aligned} & -\frac{P_m}{\tau_m} + \sum_{s=m+1}^{\infty} \frac{P_s}{\tau_{s \rightarrow m}} \\ & -\frac{P_m - P_m^0}{\tau_{l,m}} \\ & -\Gamma_{m \rightarrow m+v} P_m + \Gamma_{m+v \rightarrow m} P_{m+v} \\ & -\Gamma_{m \rightarrow m-v} P_m + \Gamma_{m-v \rightarrow m} P_{m-v} \\ & -2N_0 \sum_{s=0}^{\infty} R_{m,s}^* (P_m P_s - P_m^0 P_s^0) \\ & + \sum_{s=0}^{\infty} \frac{1}{\tau_{m,s}} (P_s \rho_m - P_m \rho_s) N(|m-s|\delta) \\ & + \sum_{s=s_a}^{\infty} \frac{P_s}{\tau_{g,s}} \end{aligned}$$

QP transitions in and out with spontaneous phonon emission

QP losses other than recombination

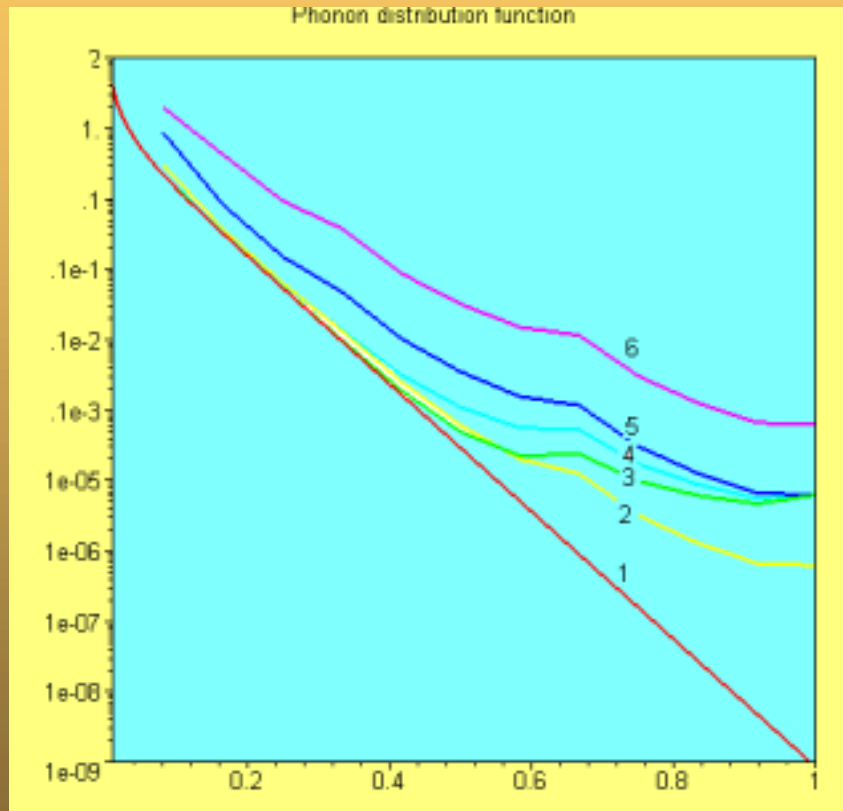
Direct tunnelling and cancellation
Back-tunnelling and cancellation

QP recombination

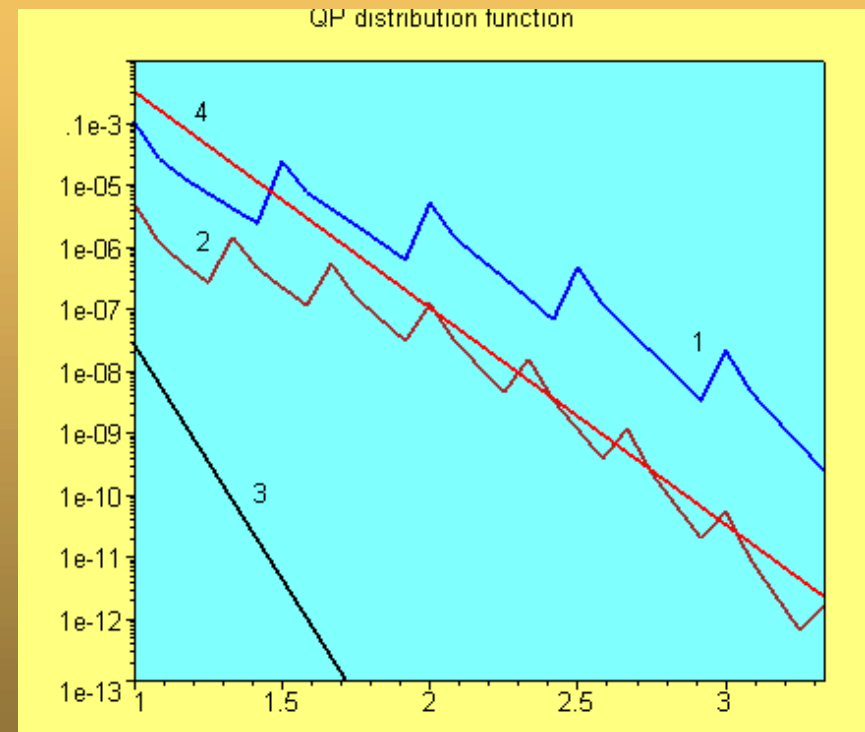
QP transitions due to absorption and stimulated emission of non-equilibrium phonons (mostly sub-gap phonons)
QP generation



Quasiparticle and phonon distribution functions

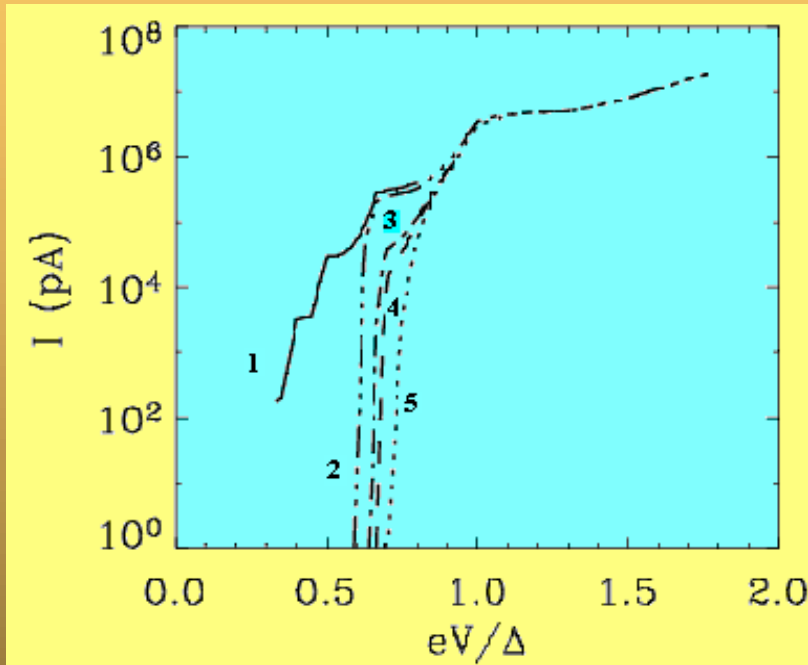


Phonon distribution "supported" by calculated QP distribution at $eV_b=1/3$.
1. thermal; 2-6 – different coupling to bath.

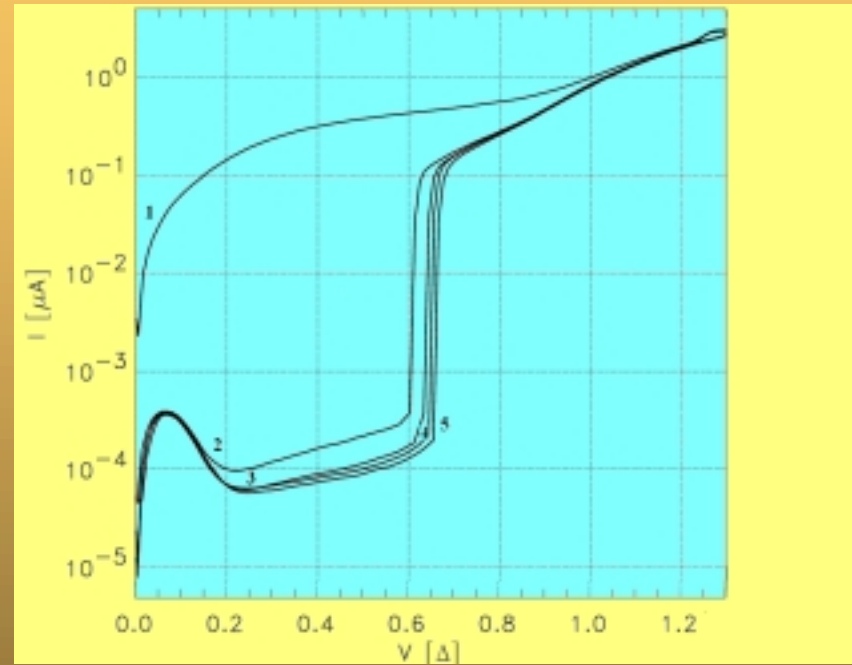


QP distribution functions:
1. $eV_b=1/2$; 2. $eV_b=1/3$; 3. at thermal equilibrium; 4. "equilibrium" with the same QP density.

Current voltage characteristics



Calculated I-V curves: 1. no loss;
2-5 with loss times 500, 120, 110
and 100 microseconds respectively
 $T_0 = 100\text{mK}$

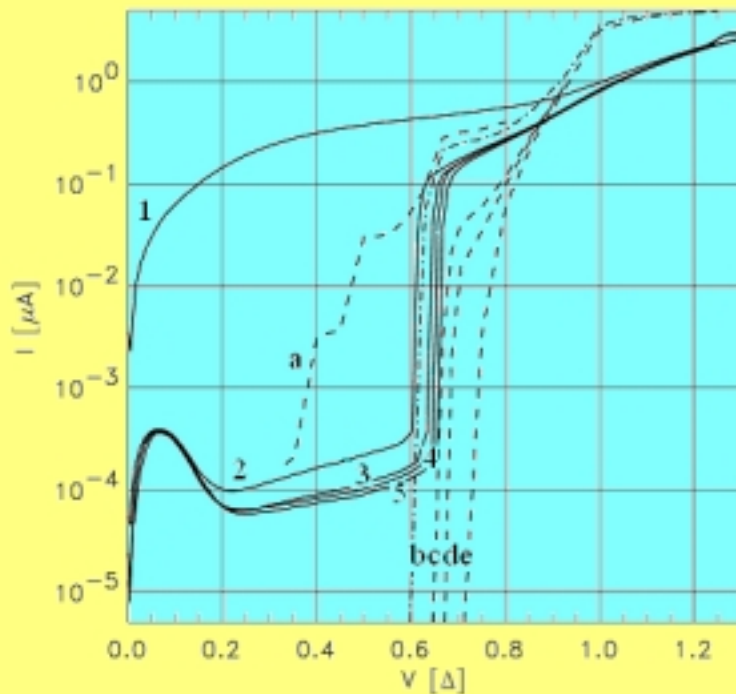


Measured I-V curves: 1. $T_0 = 350\text{mK}$;
2. $T_0 = 150\text{mK}$; 3. $T_0 = 130\text{mK}$;
4. $T_0 = 100\text{mK}$; 5. $T_0 = 40\text{mK}$

KJL275:

100nm Ta/265nm Al/AlOx/265nm Al/100nm Ta

Current voltage characteristics



Calculated I-V curves: a. no loss;
b-e with loss times 500, 120, 110 and
100 microseconds respectively
 $T_0 = 100\text{mK}$

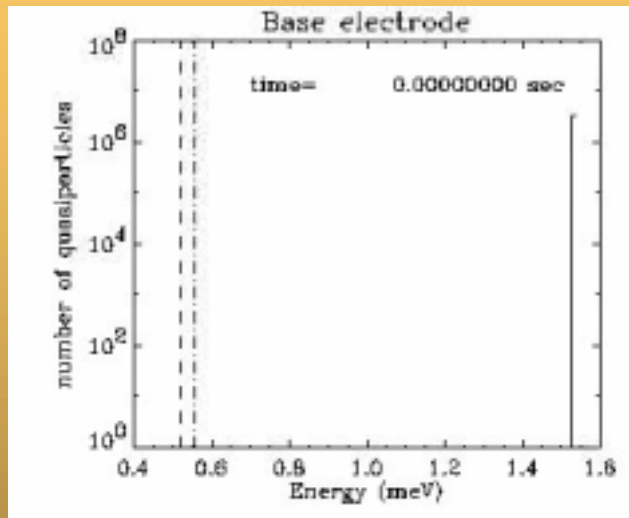
Measured I-V curves: 1. $T_0 = 350\text{mK}$;
2. $T_0 = 150\text{mK}$; 3. $T_0 = 130\text{mK}$;
4. $T_0 = 100\text{mK}$; 5. $T_0 = 40\text{mK}$

KJL275:

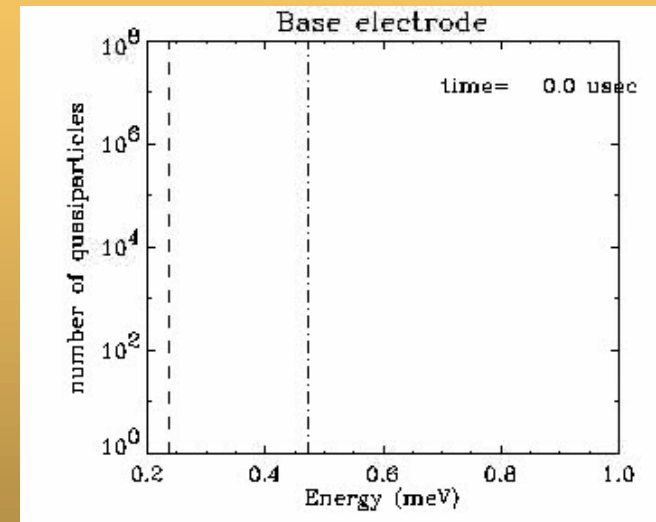
100nm Ta/265nm Al/AlOx/265nm
Al/100nm Ta



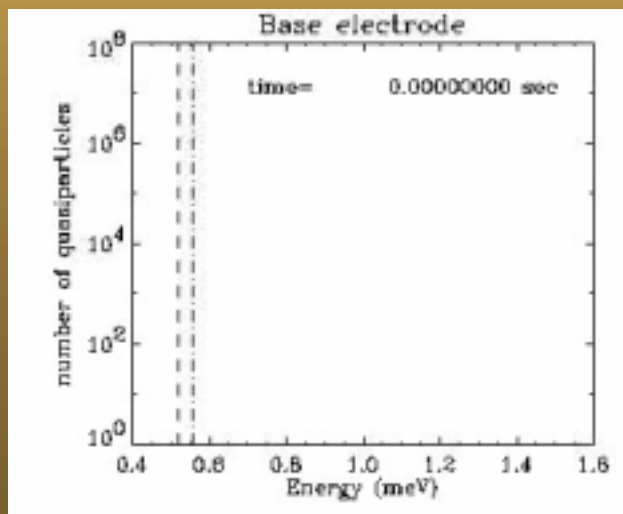
Temporal evolution of the QP distributions in the biased STJ



$V_b = 34$ microvolts
Initially monochromatic distribution below the Active region threshold



KJL275
 $V_b = 235$ microvolts
Self-generation not included



$V_b = 34$ microvolts
Initially monochromatic distribution at the edge



Summary

- We have presented evidence, both theoretical and experimental, for the existence of a new non-equilibrium qp state in low gap, low loss STJs;
- The formation of broad non-monotonic spectral distribution of QPs invalidates classical RT model;
- We derived a set of spectral balance equations from the system of kinetic equations for interacting QPs and phonons in superconductors
- Even in the absence of QP self-generation the STJ responsivity and signal decay times and their variation with bias voltage and bath temperature strongly depend on details of QP and phonon distribution