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Extending Single-Photon Optimized Superconducting Transition Edge Sensors Beyond the Single-Photon Counting Regime

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The power gap

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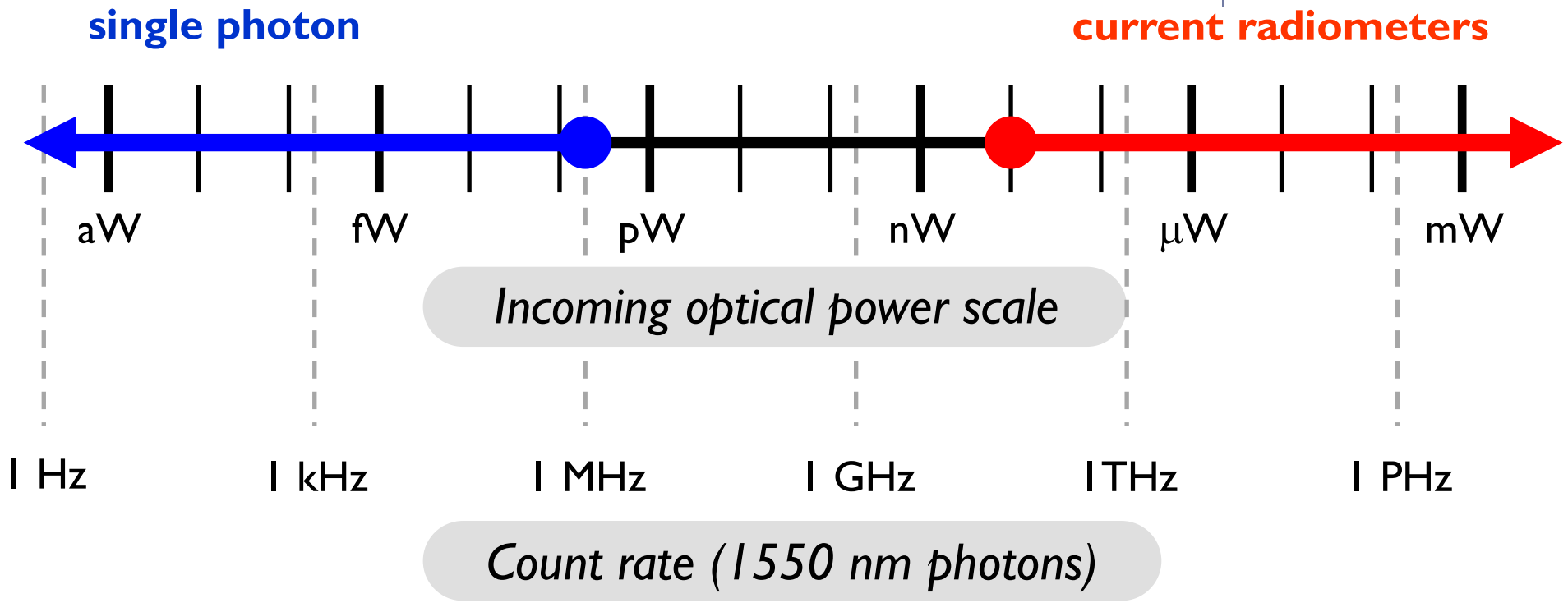

no NMI-traceable single-photon sources or detectors

Transition Edge Sensor

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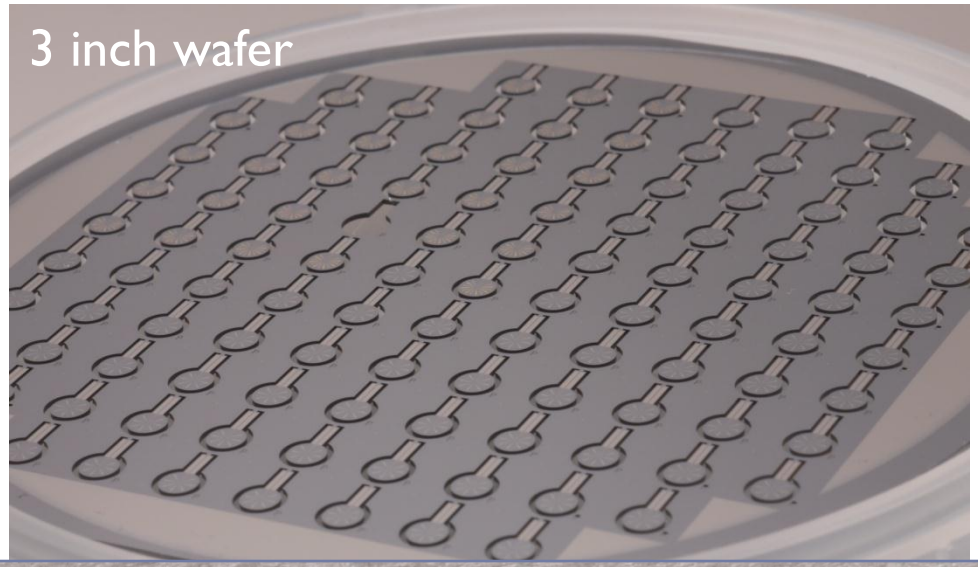
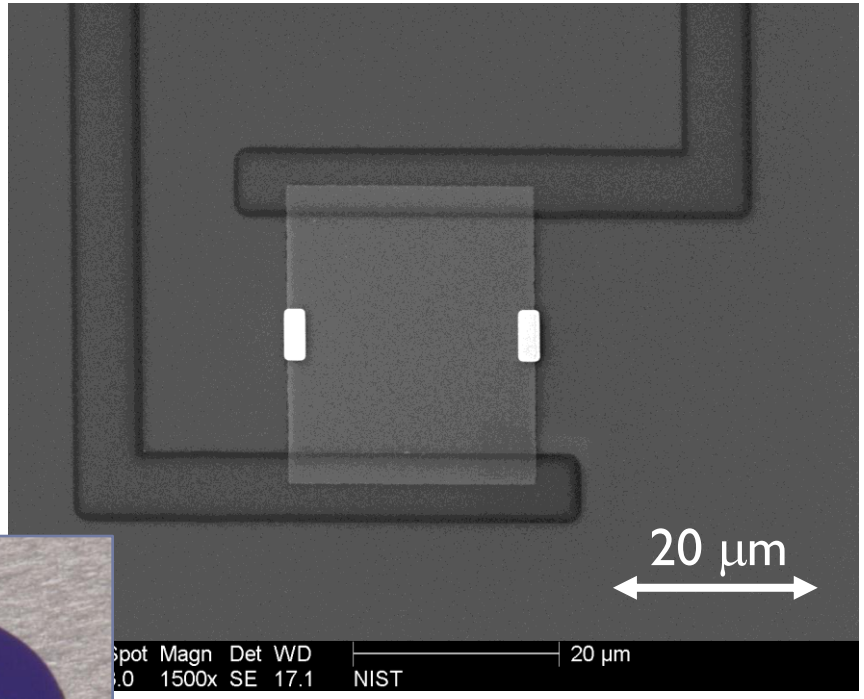
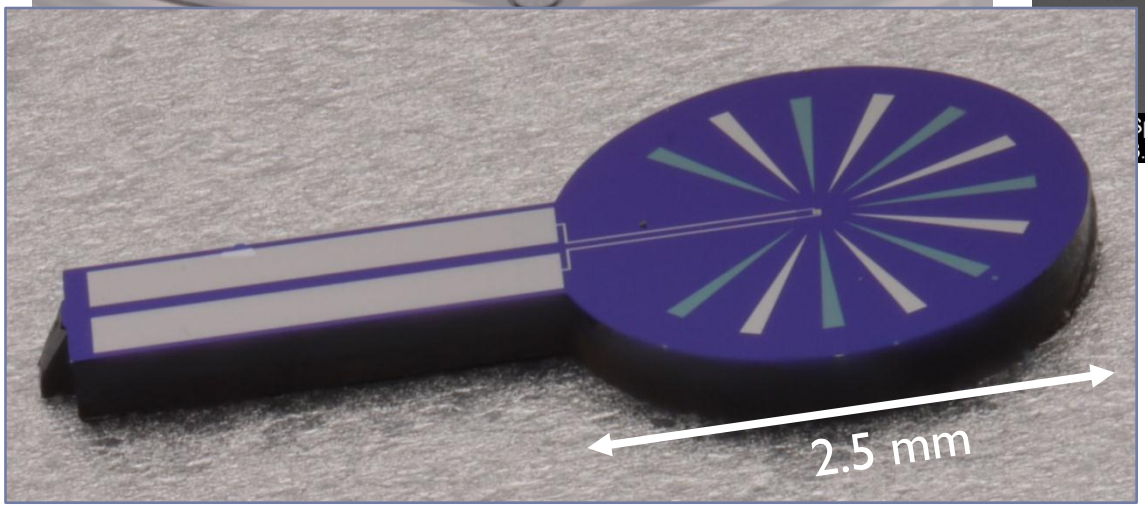
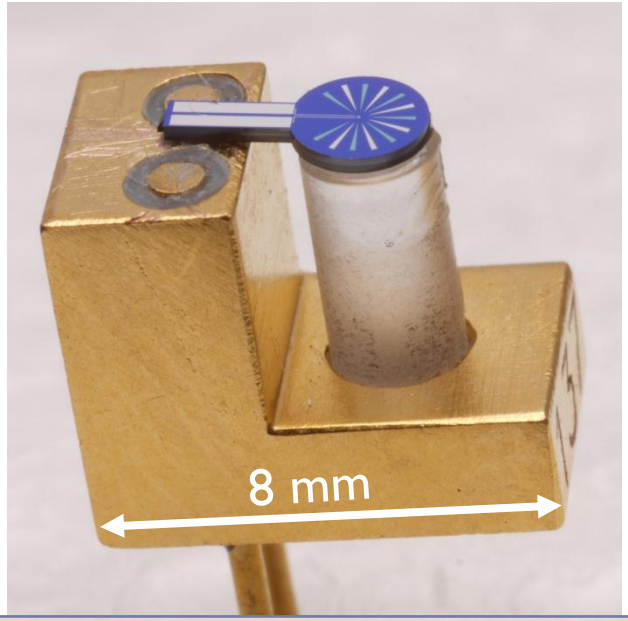


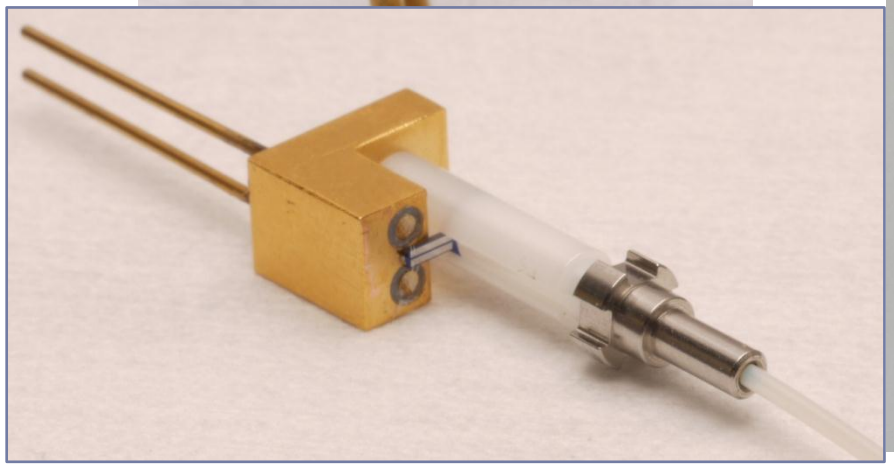


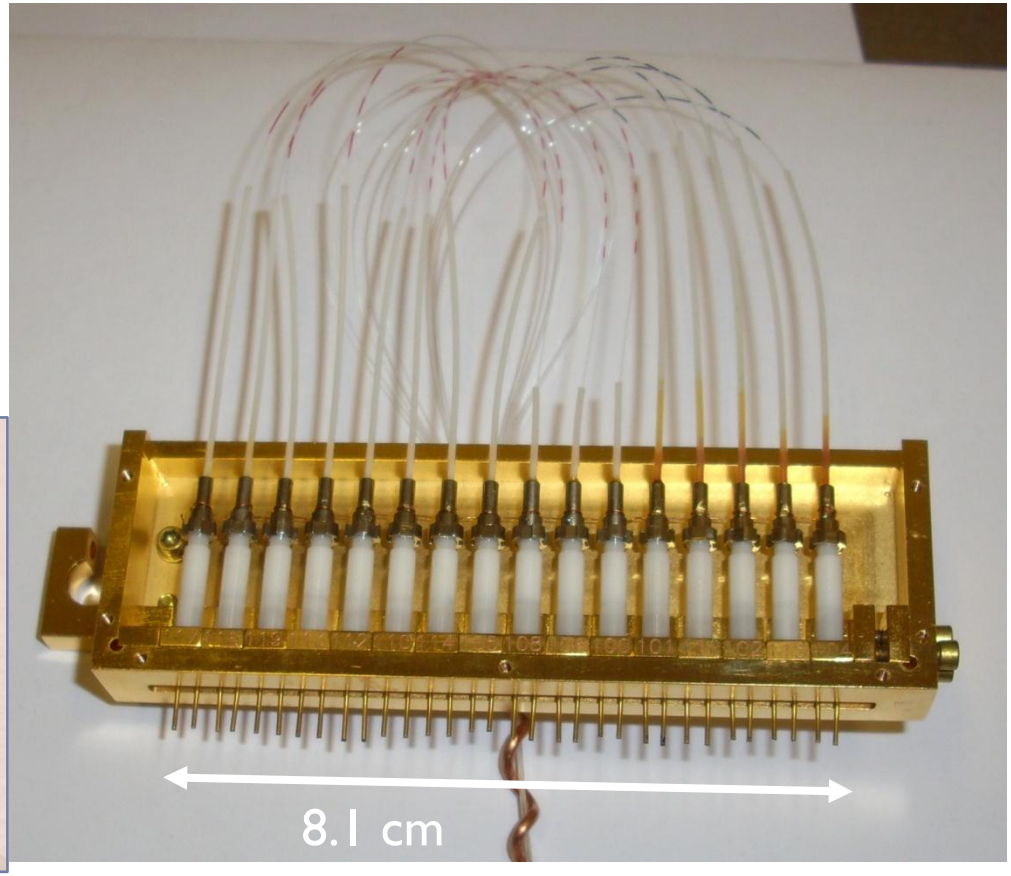


- Thin film optical stack
- Near 100% efficient

Transition Edge Sensor







Transition Edge Sensor Single photons

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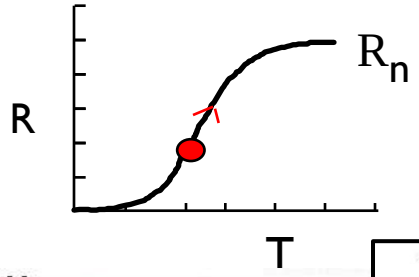
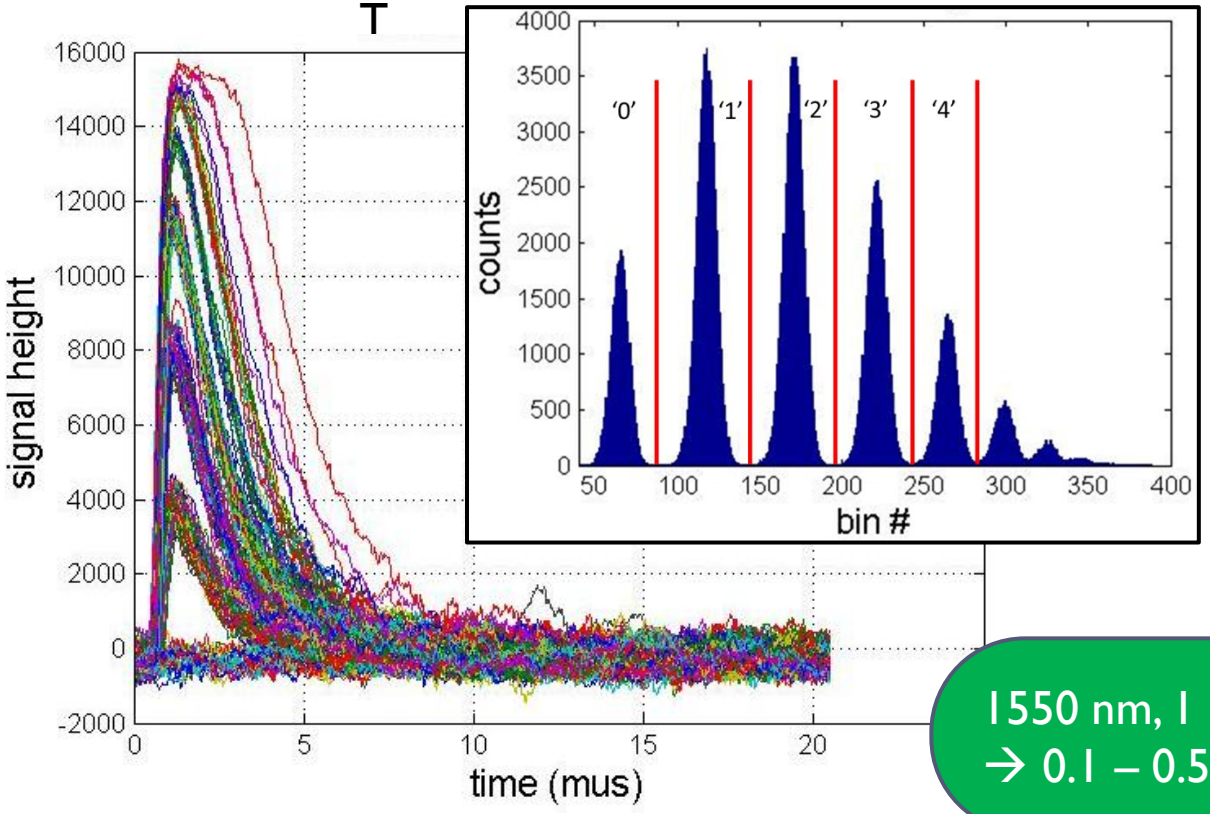
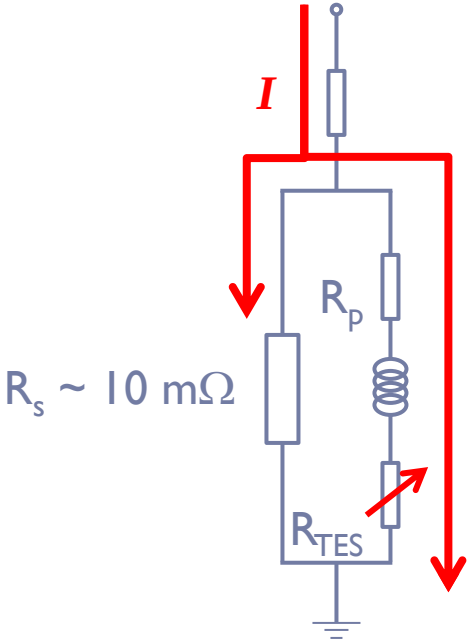
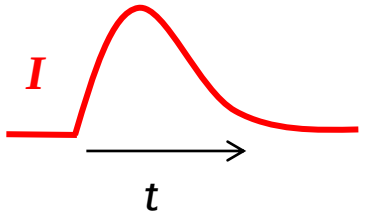


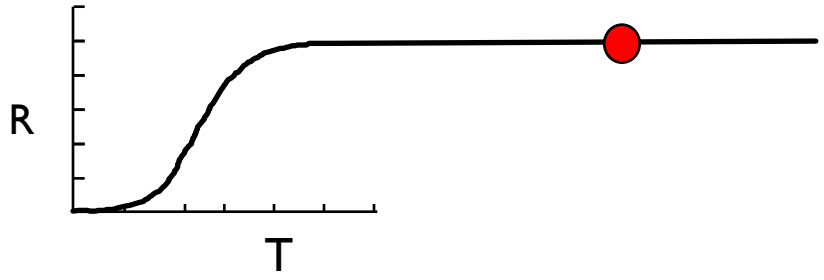


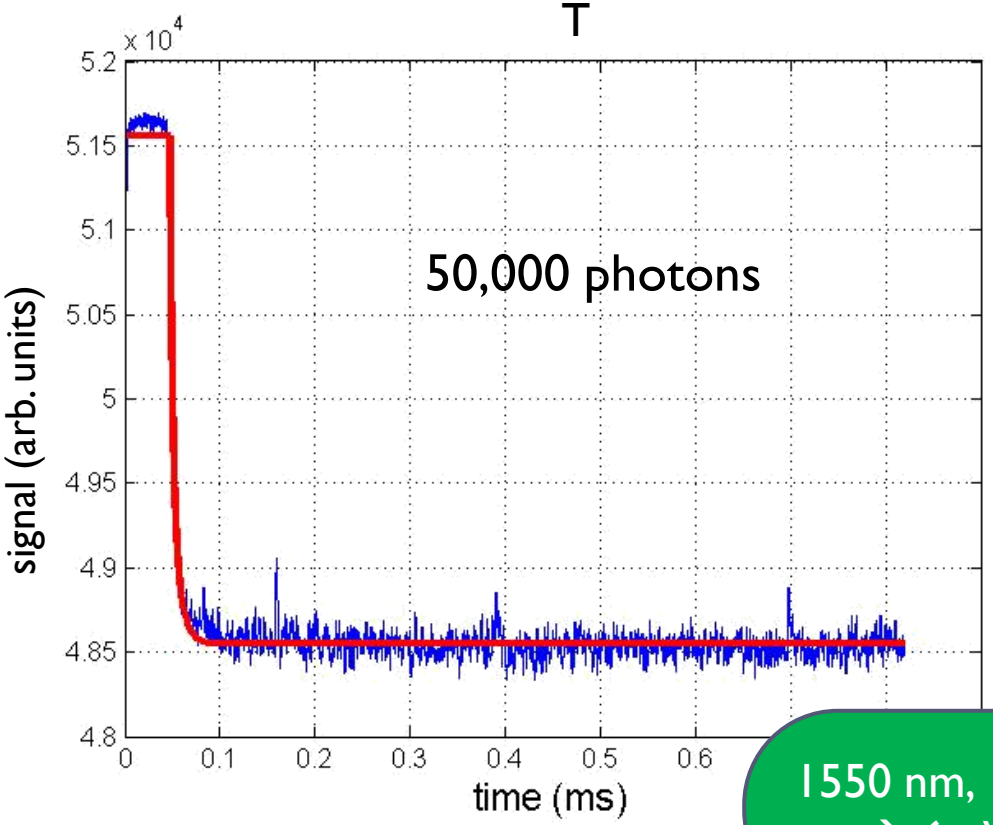




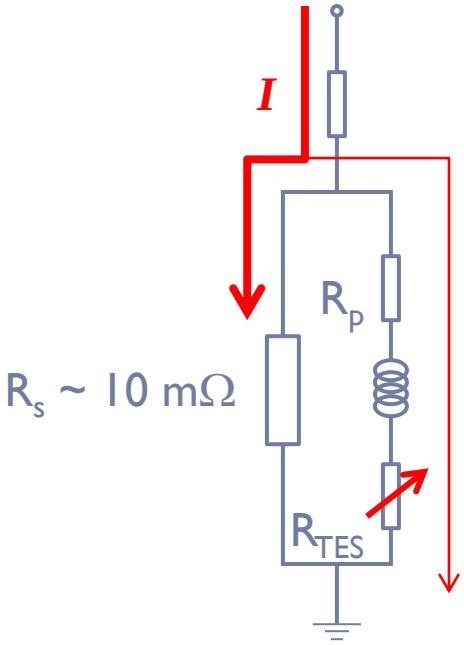
1550 nm, 1 kHz
→ 0.1 – 0.5 fW

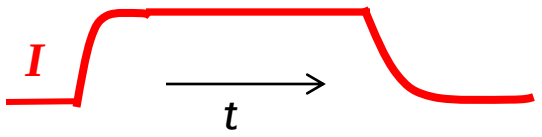
Beyond Single Photon Counting Temporal Traces



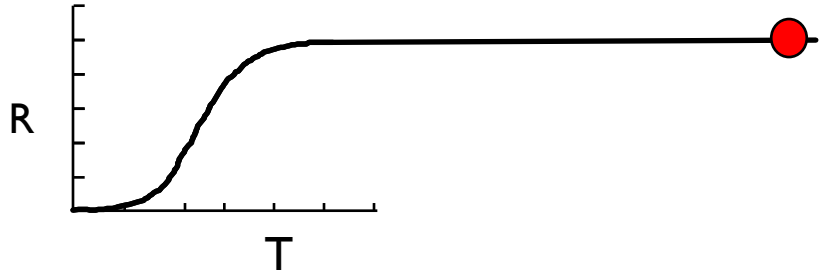


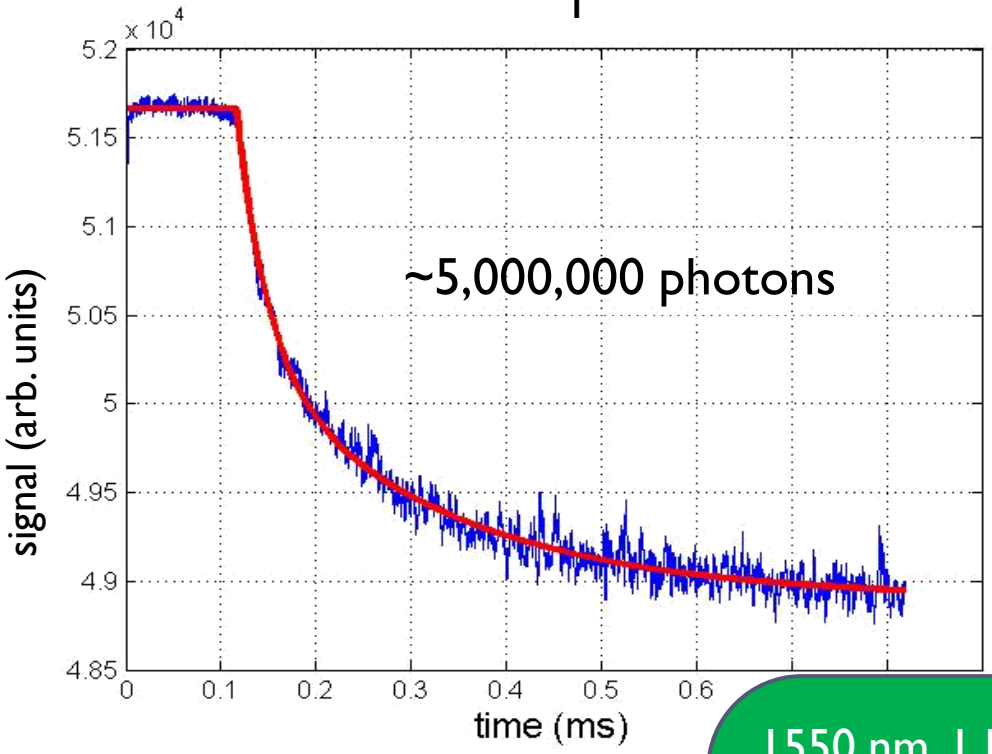
1550 nm, 1 kHz
→ 6 pW



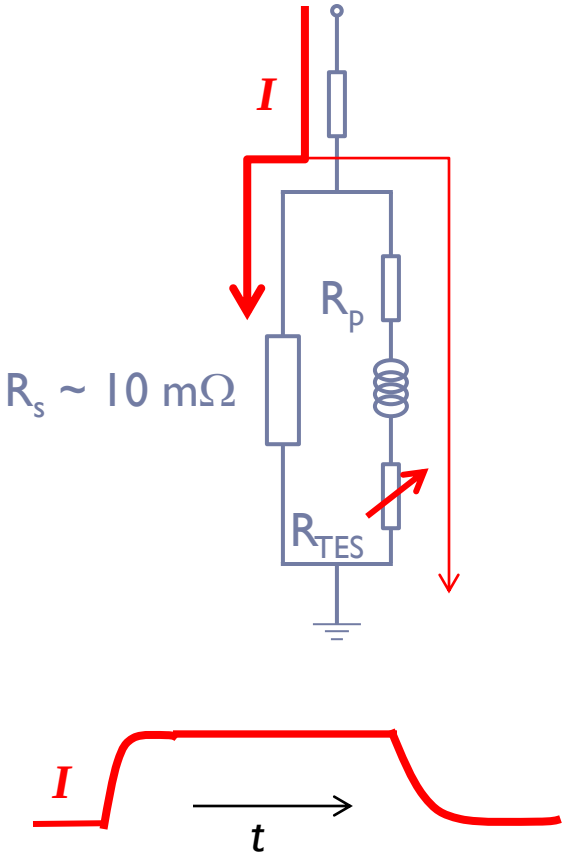


Beyond Single Photon Counting Temporal Traces

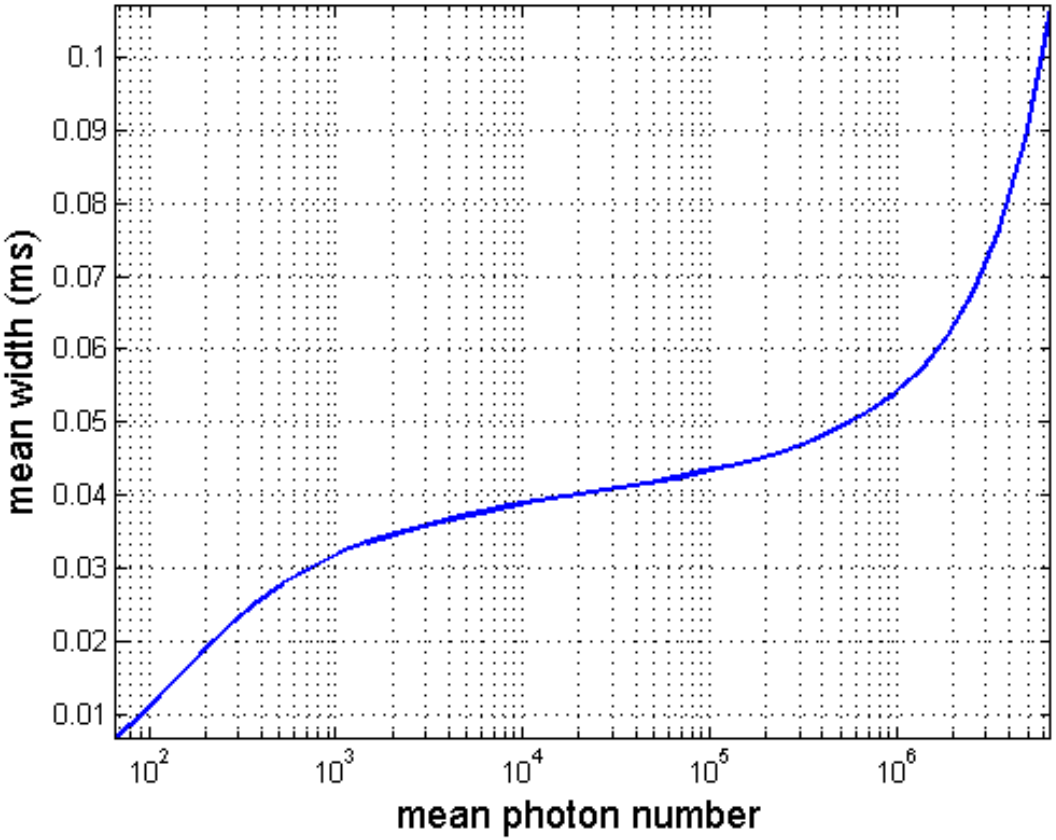


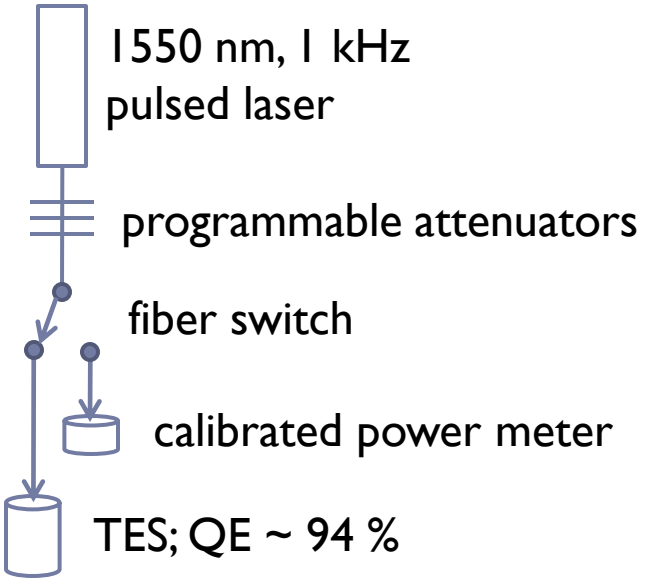


1550 nm, 1 kHz
→ 600 pW



Width measurement





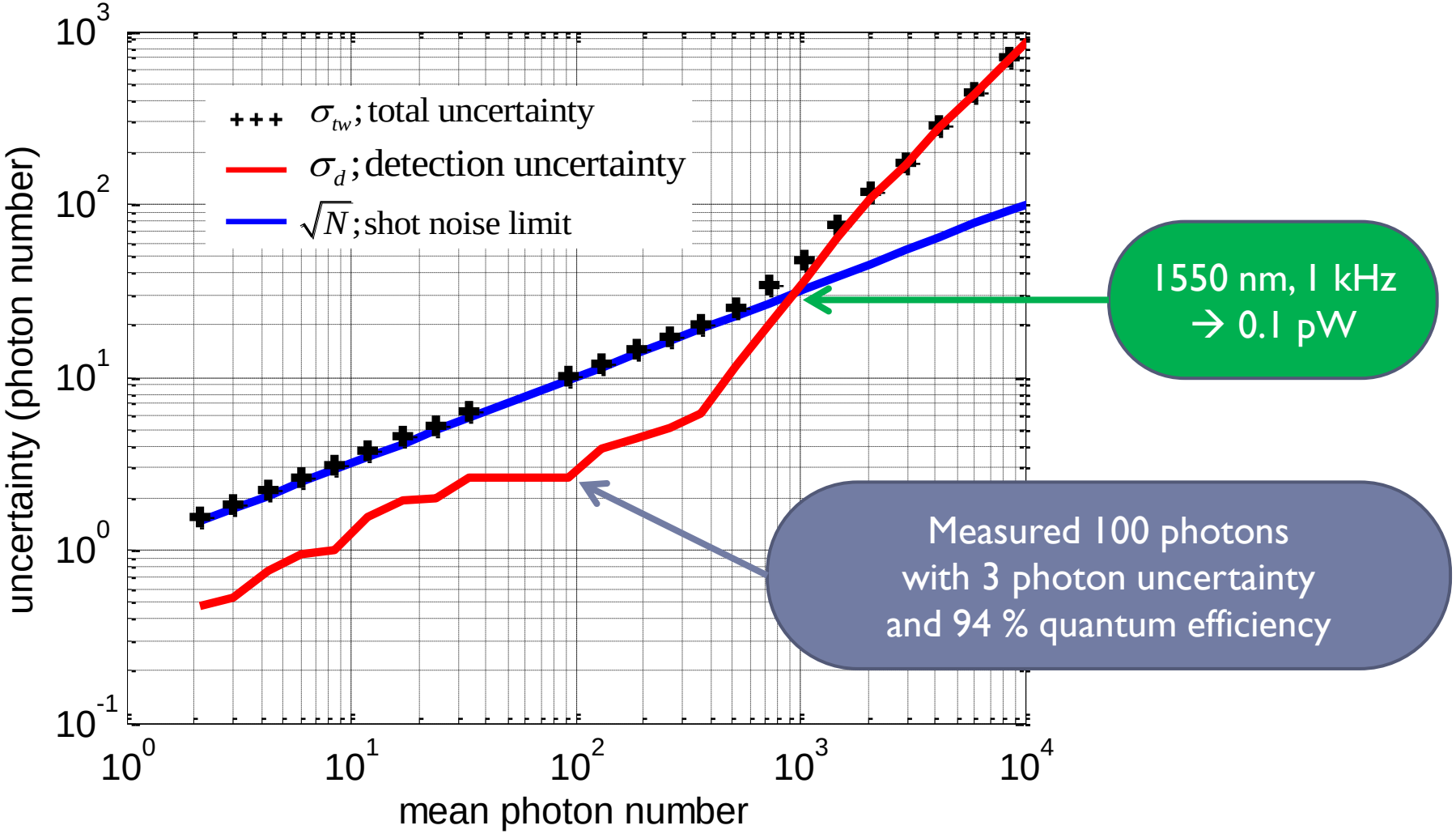
Up to 6.25 million detected photons in a single shot measurement

1550 nm, 1 kHz
→ 750 pW

input state Poisson distribution:

$$\sigma_{input} = \sqrt{N}$$

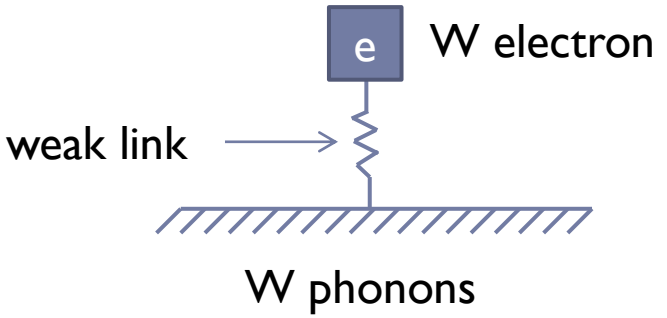
Photon number uncertainty

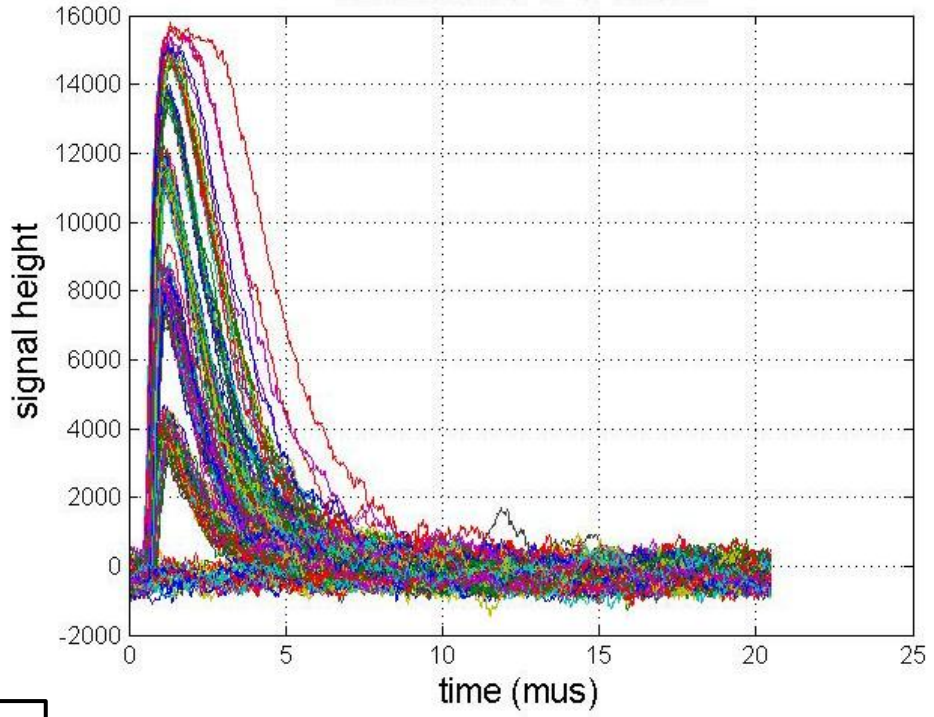


1550 nm, 1 kHz
→ 0.1 pW

Measured 100 photons
with 3 photon uncertainty
and 94 % quantum efficiency

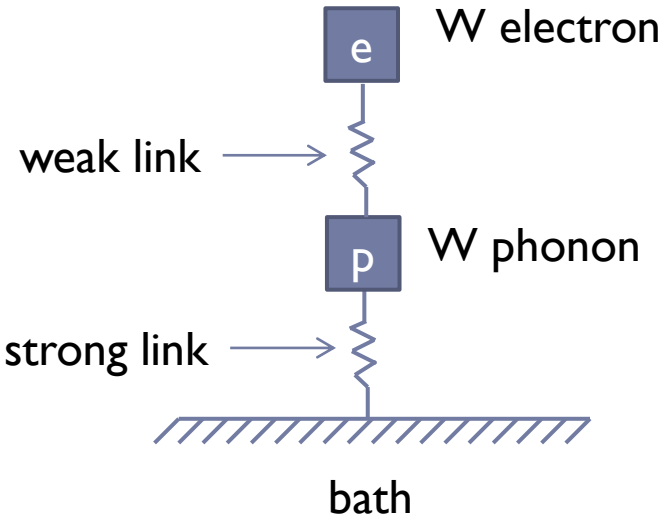
TES modeling – 1 body

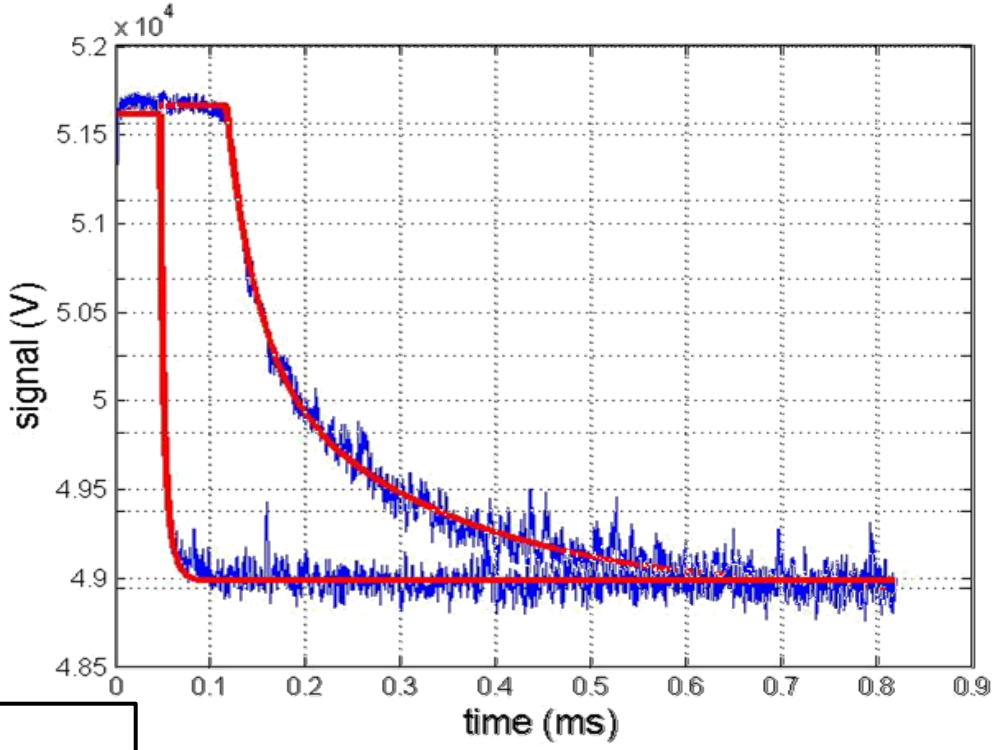




$$C_e \frac{dT_e}{dt} = -\kappa_{e-p}\left[T_e^5 - T_p^5\right] + \delta\left(P_\gamma - P_l\right)$$

TES modeling – 2 body

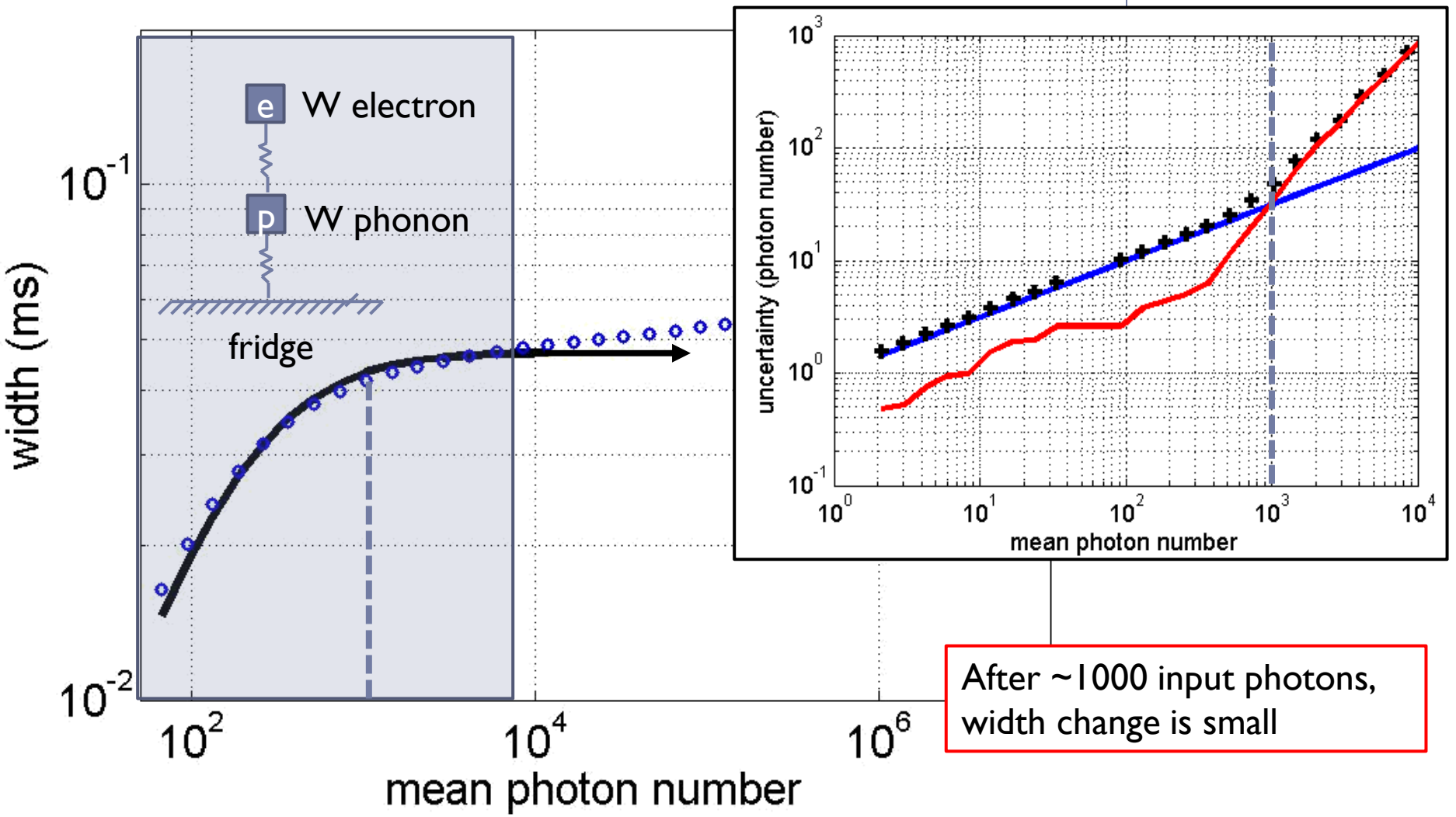




$$C_e \frac{dT_e}{dt} = -\kappa_{e-p}\left[T_e^5 - T_p^5\right] + \delta\left(P_\gamma - P_l\right)$$

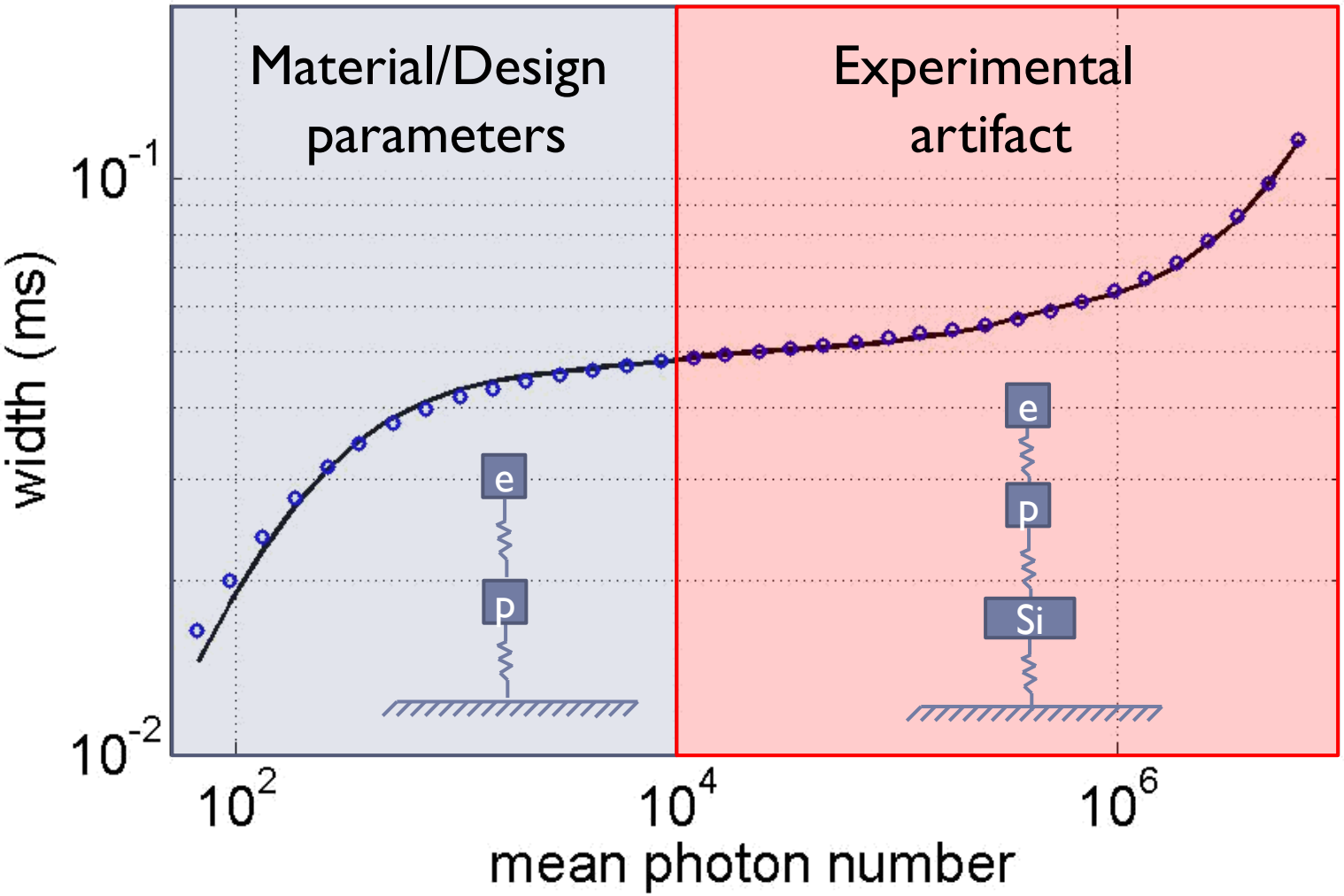
$$C_p \frac{dT_p}{dt} = -\kappa_{p-Si}\left[T_p^4 - T_{Si}^4\right] + C_e \frac{dT_e}{dt}$$

Less sensitive over 1000 photons

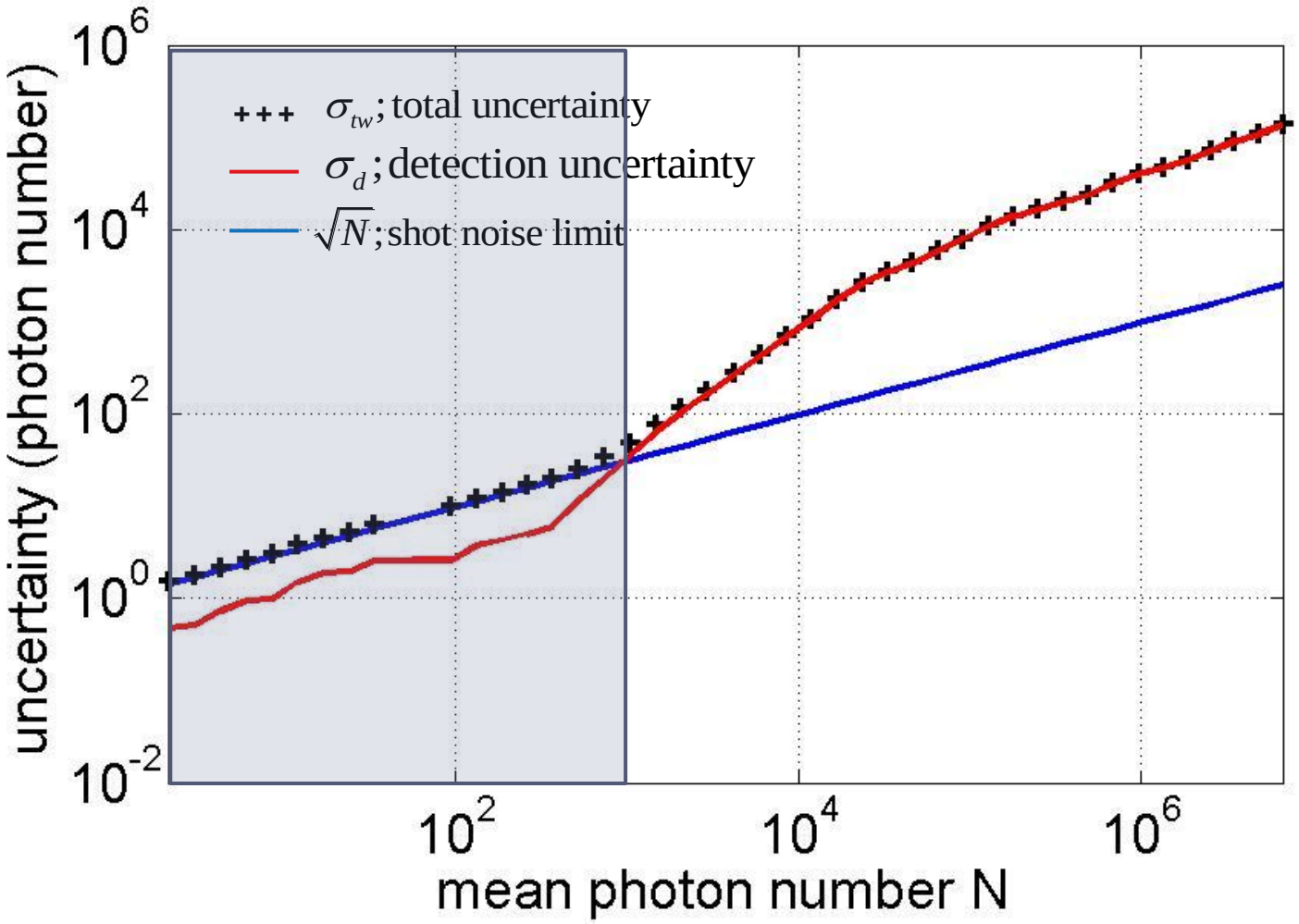


After ~1000 input photons, width change is small

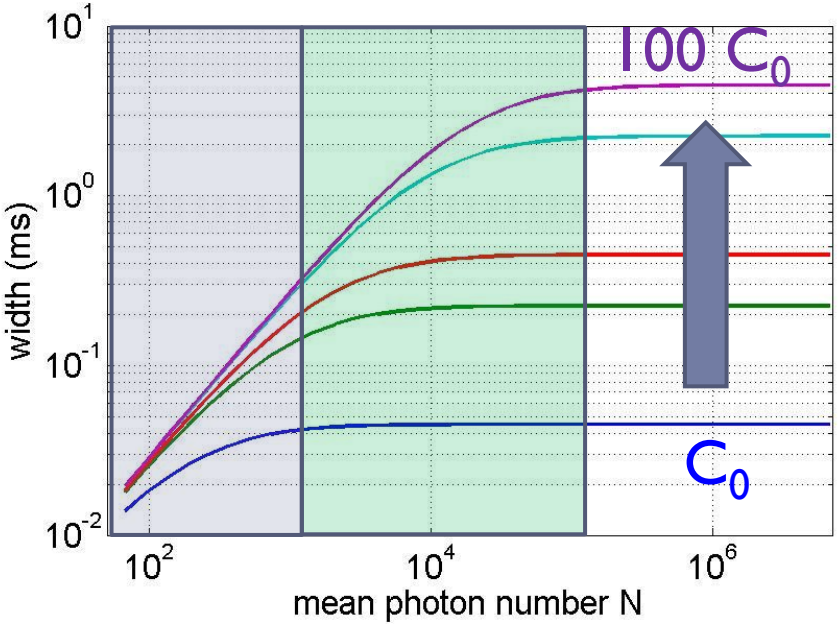
Changing Si/bath temperature

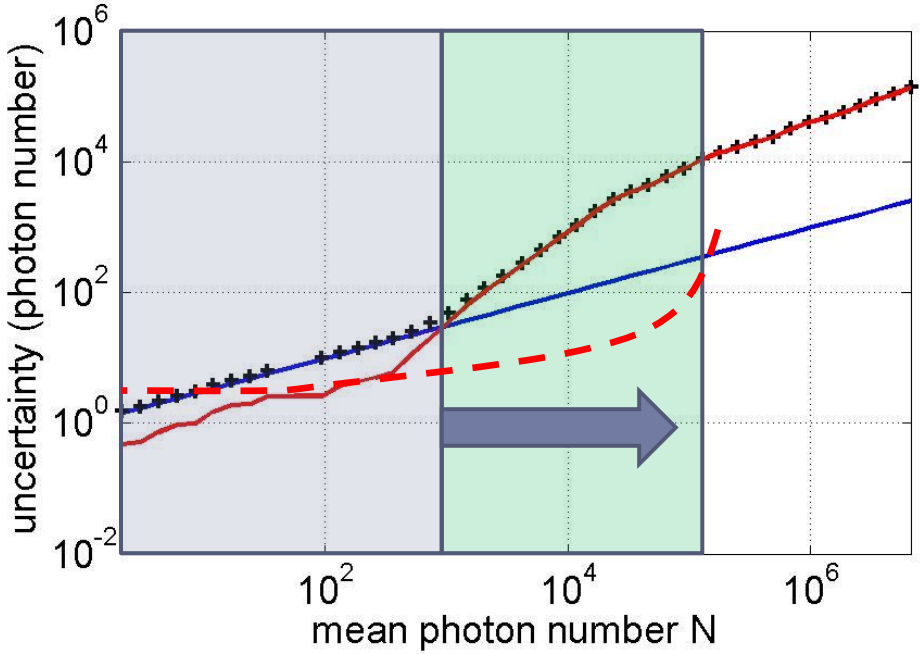


Desirable operating region



How to increase range?

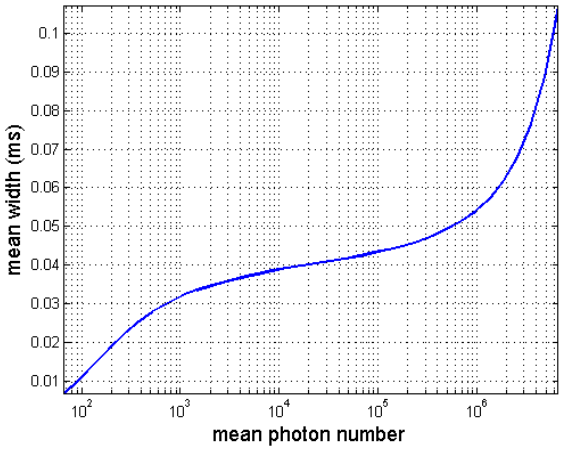


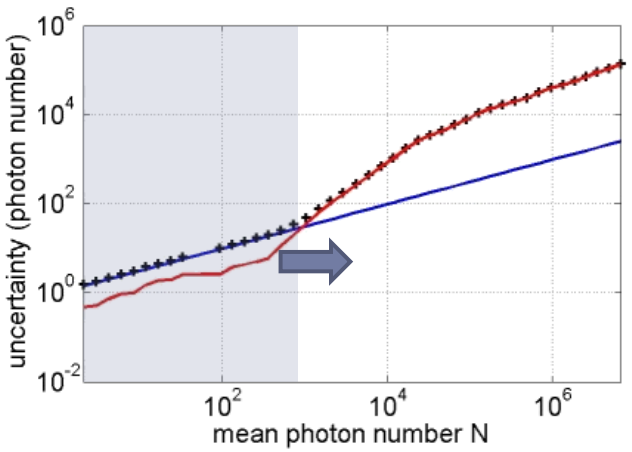


Material/design: Increase TES volume to allow for smaller temperature changes

Conclusions

- Measurement of more than 6 million photons in a single laser pulse with 94 % efficiency
- Shot-noise limited detection for up to 1,000 photons (0.1 pW @ 1 kHz)
- Larger TES will push the shot-noise limit further to > 10,000 photons





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Dynamic solutions at low power

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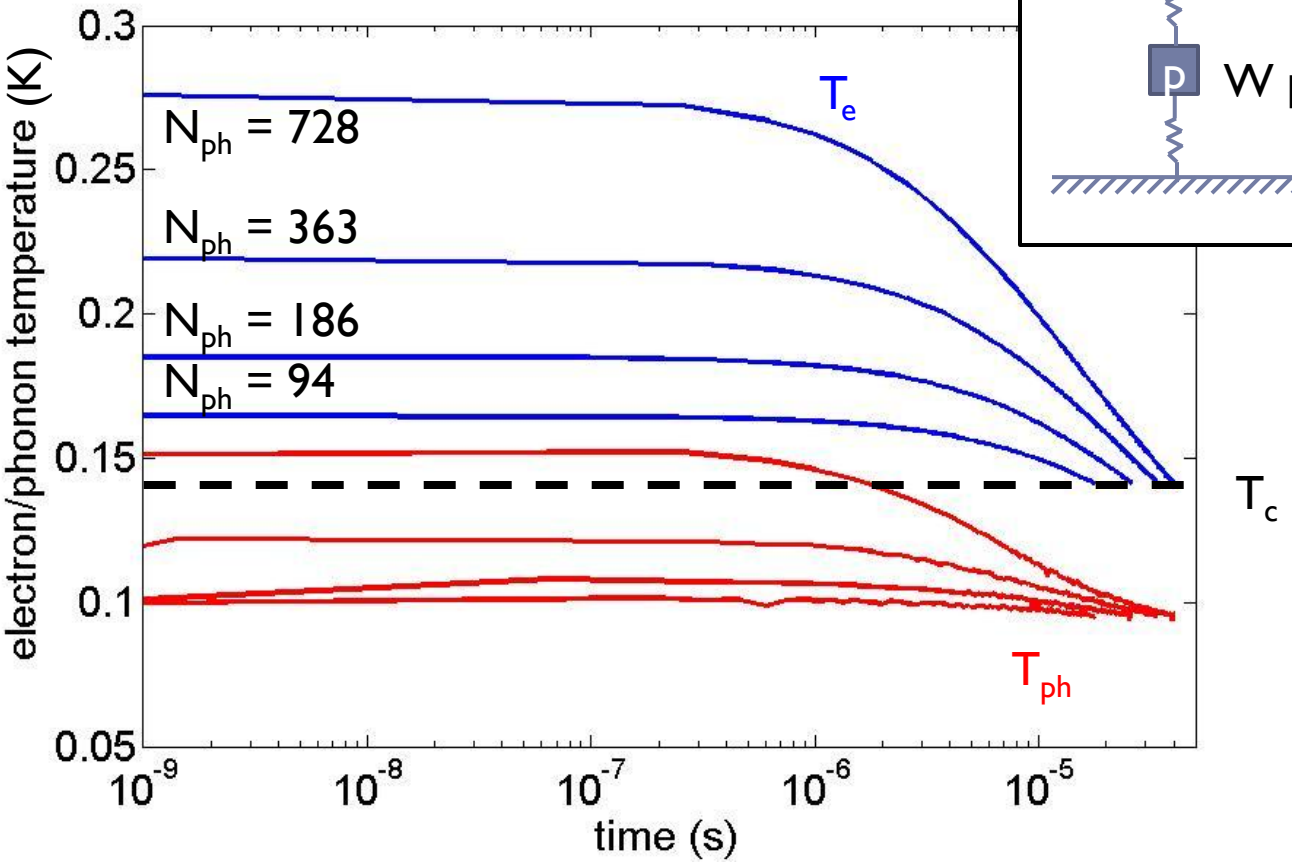
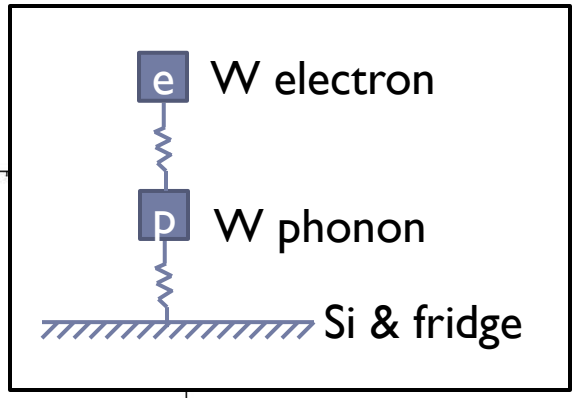
$T_c = 140\text{mK}$

$T_p = 90\text{mk}$





Dynamic solutions at high power