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Scaling the current from a GHz electron pump using a CCC

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Silicon electron pump @ 2 GHz

APPLIED PHYSICS LETTERS **109**, 013101 (2016)

Gigahertz single-electron pumping in silicon with an accuracy better than 9.2 parts in 10^7

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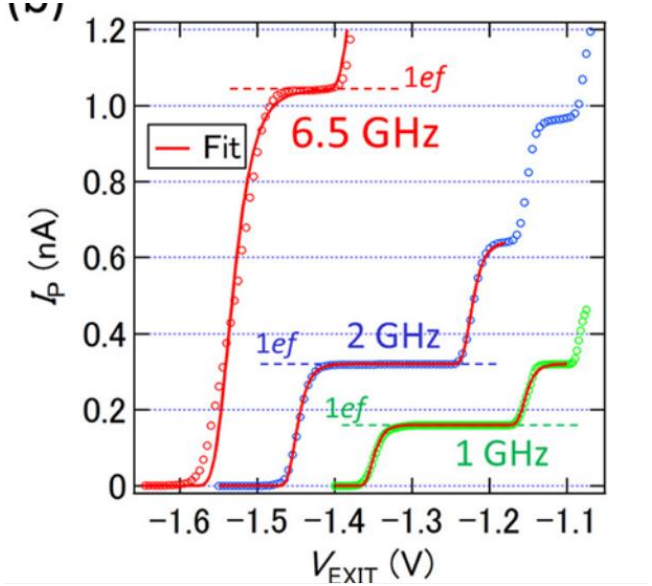
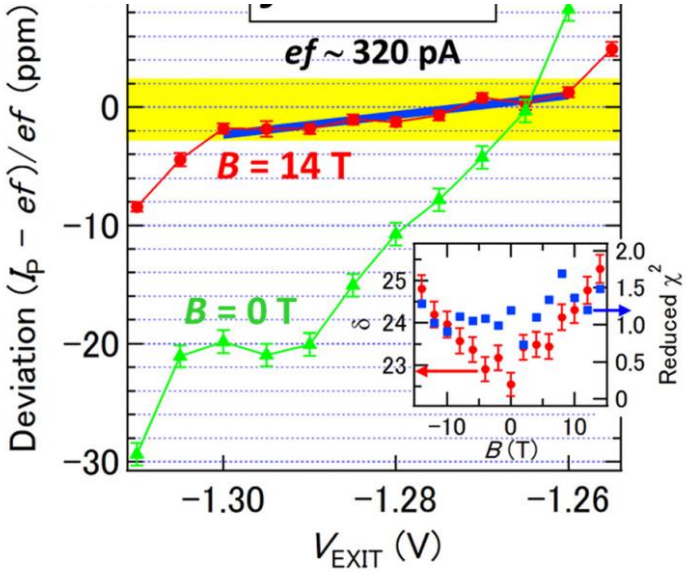
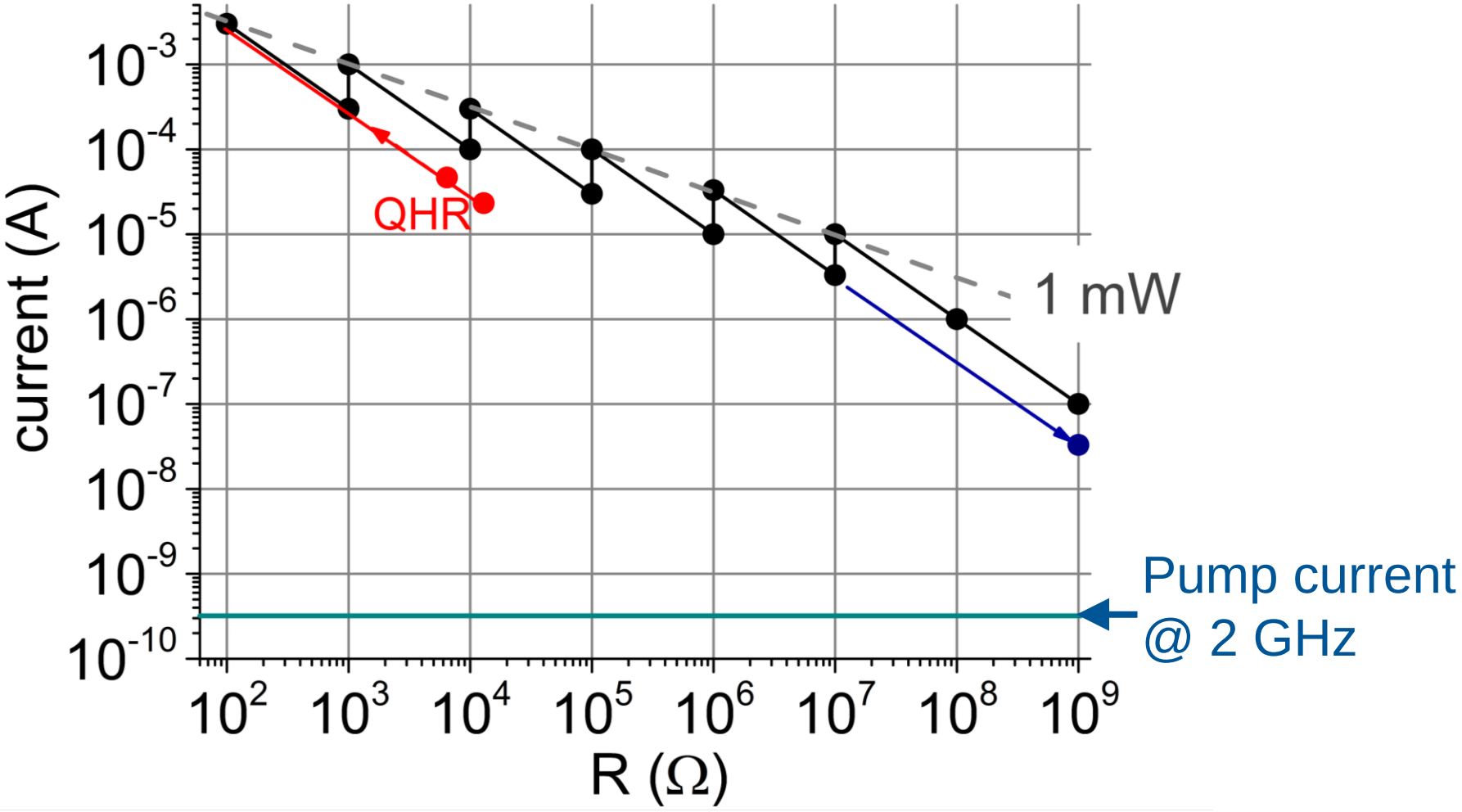
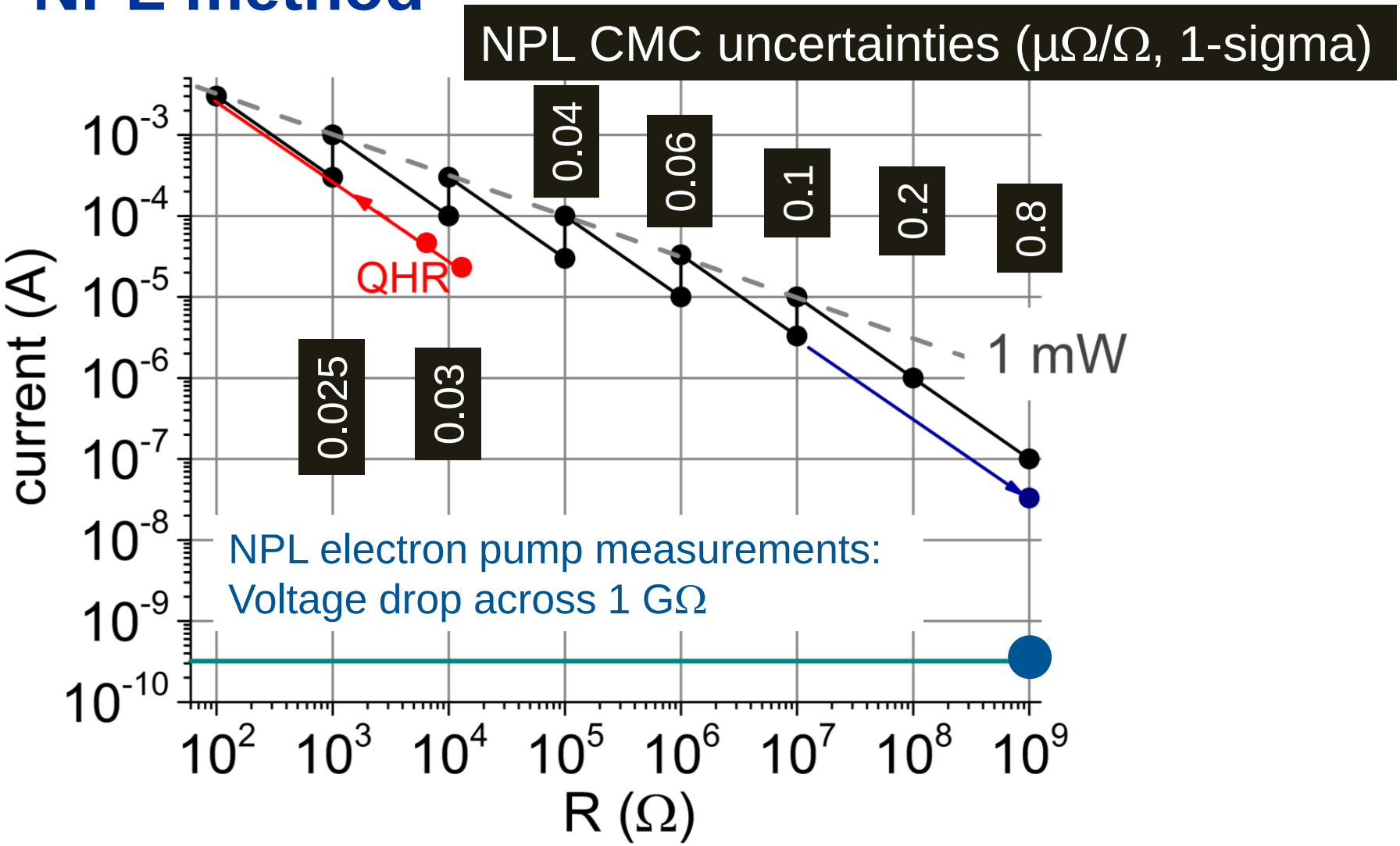




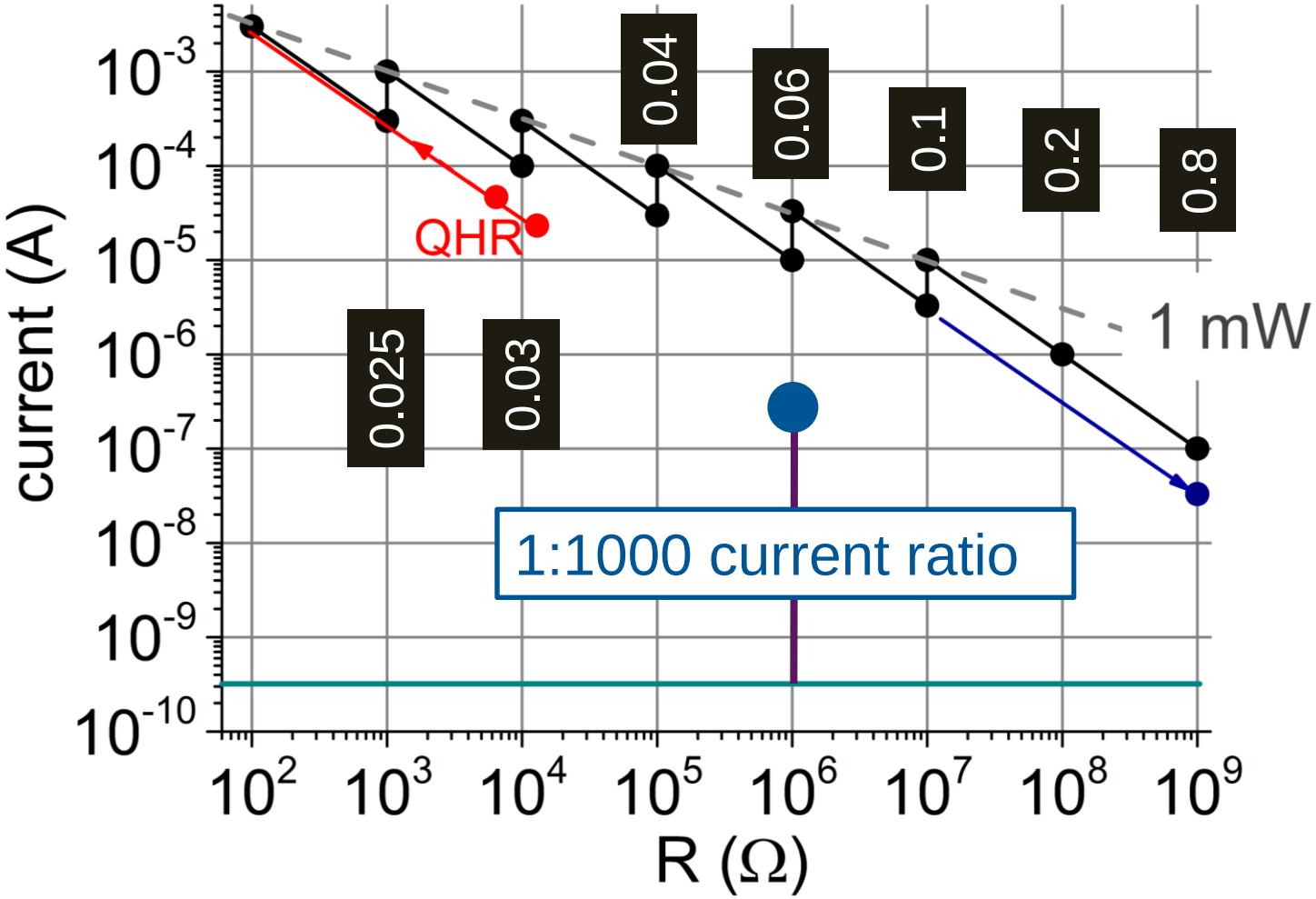
Measuring electron pumps – a scaling problem



Measuring electron pumps – NPL method



Measuring electron pumps – ULCA method



Drung et al, Rev. Sci. Instr. **84**, 024703 (2015)

Direct scaling with CCC

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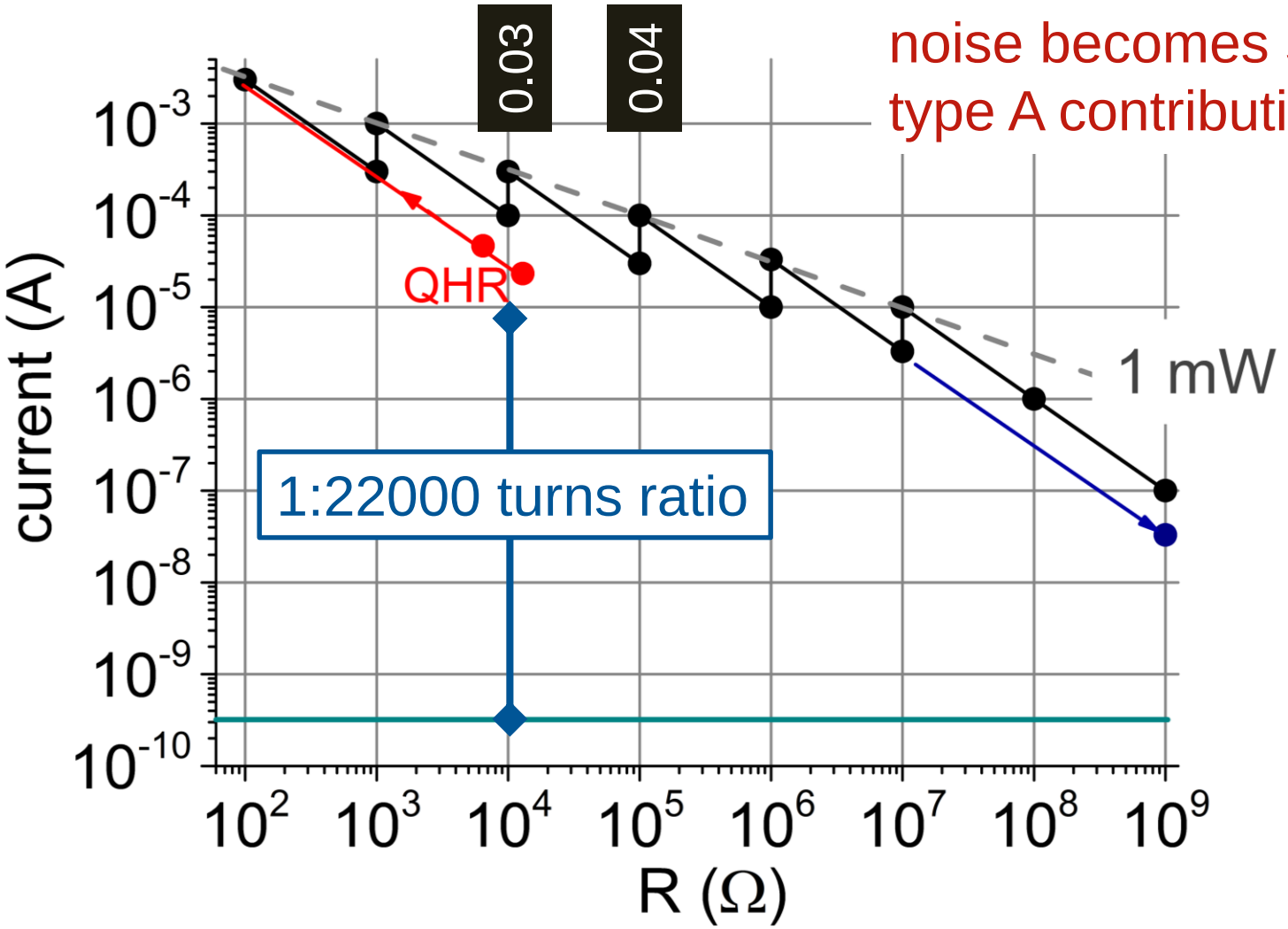
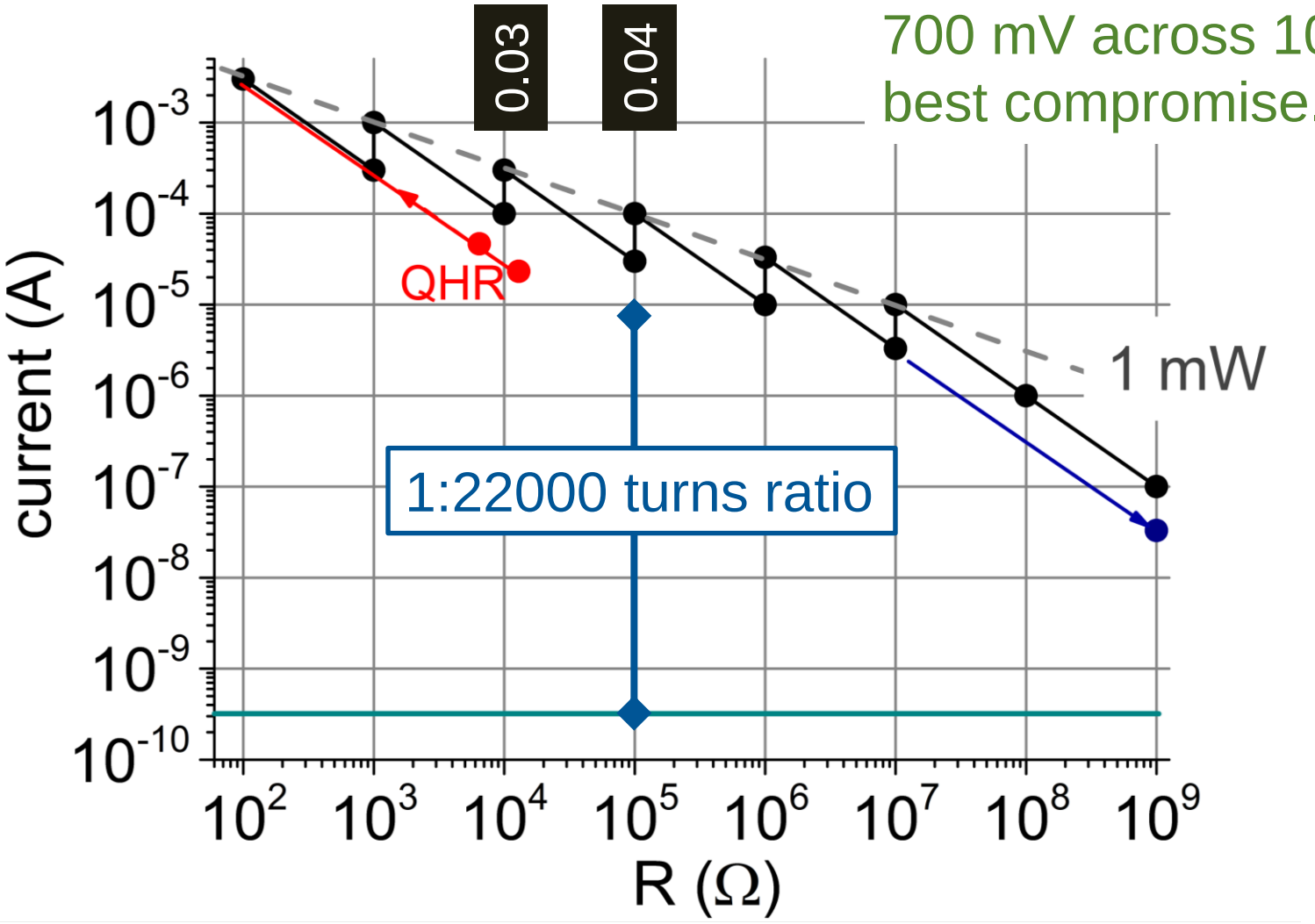
70 mV: too small, detector noise becomes significant type A contribution

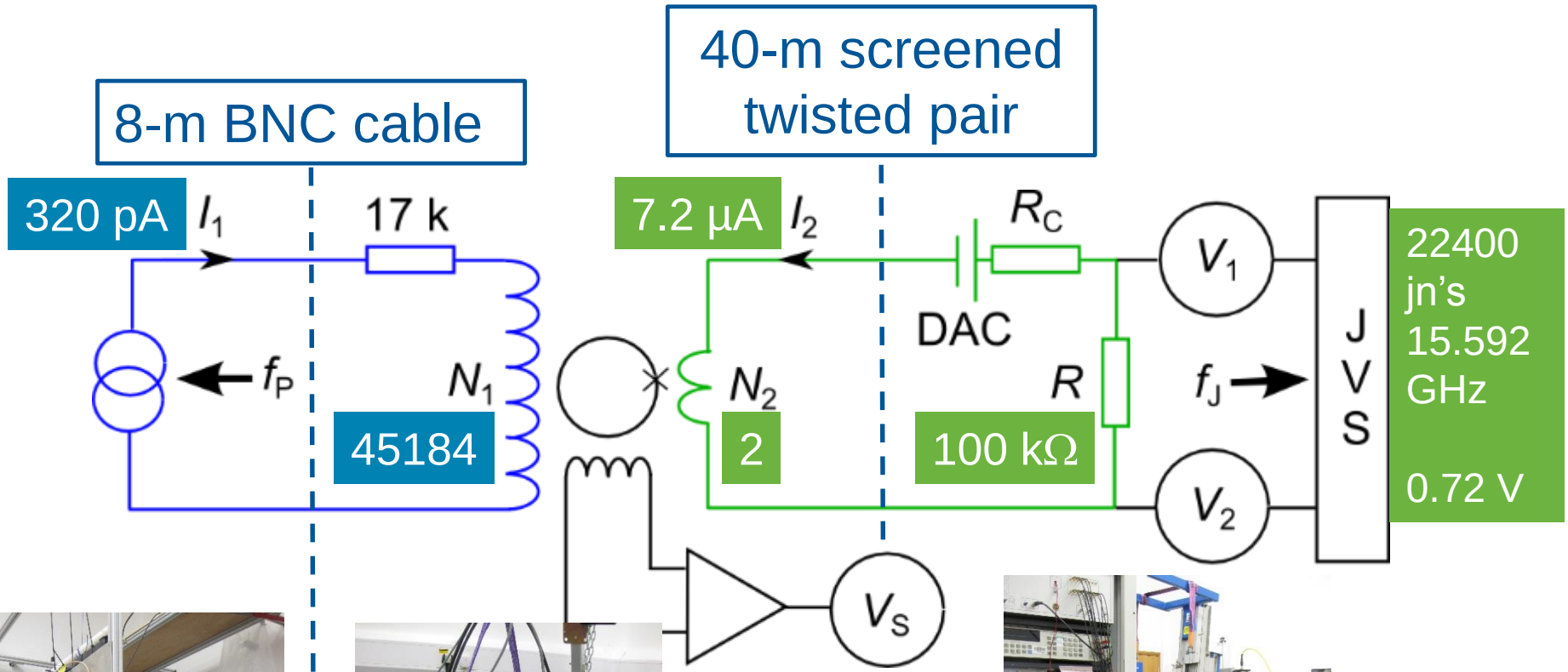


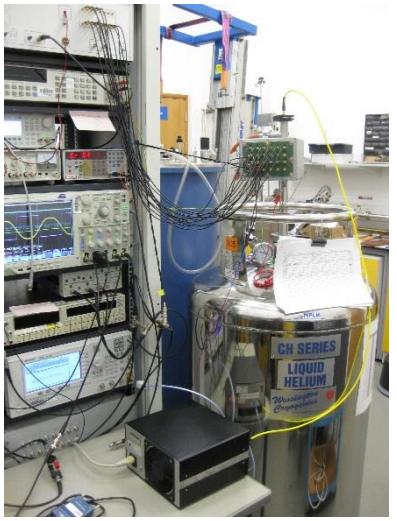
Metallic pumps: F. Piquemal and G. Geneves, Metrologia **37**, 207 (2000)
B. Steck et al, Metrologia **45**, 482 (2008)

Direct scaling with CCC



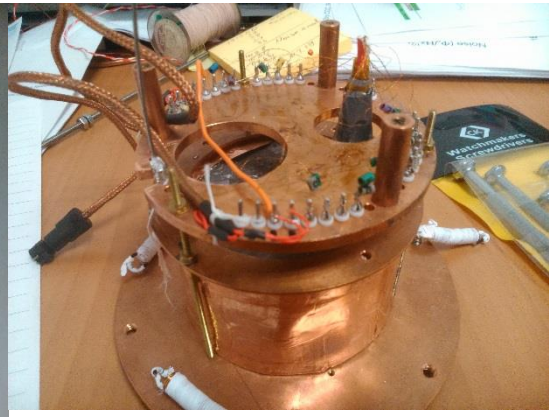
Measurement circuit

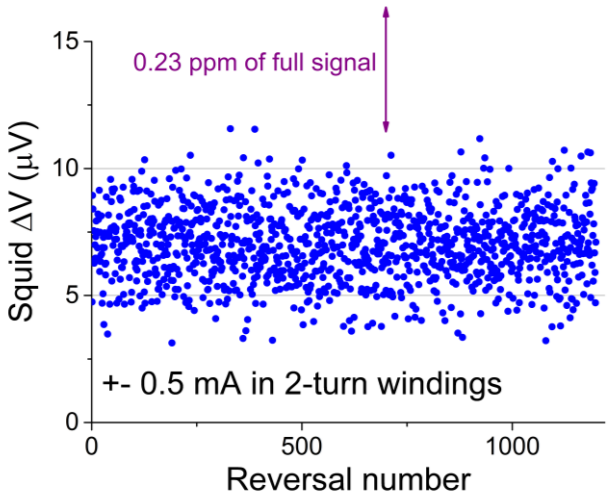




Cryogen-free CCC

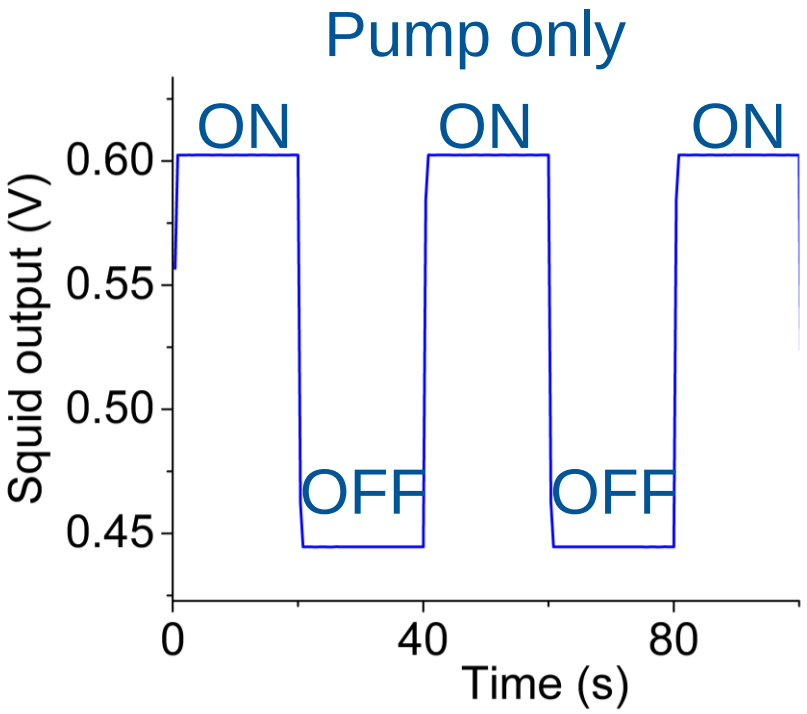
Same CCC as used in SETSAW measurements:
Janssen and Hartland, *Physica B* **284**, 1790 (2000)

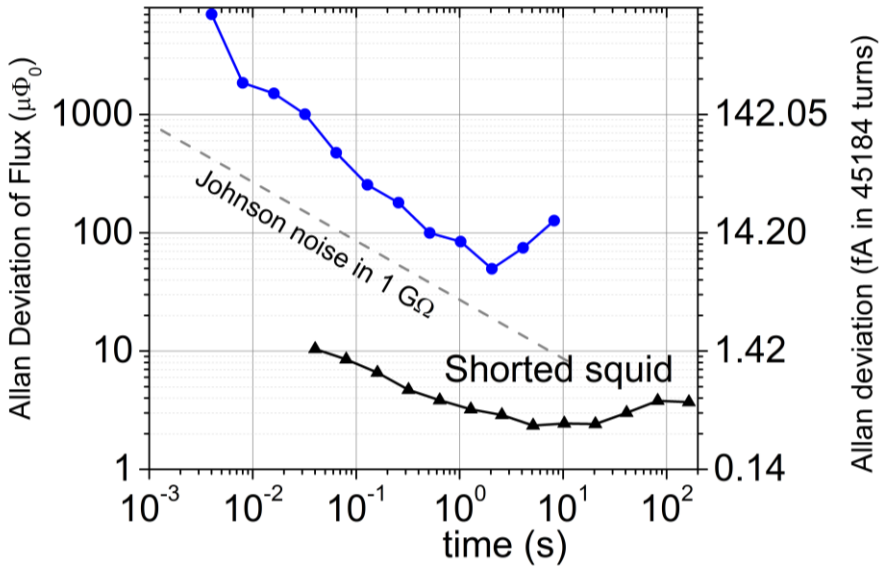




- Cryogen-free helium-3 system, 20 mK stability
- Down-leads are cotton-padded twisted pairs inside metal tube
- Defect in squid shield – 1:1 ratio error
- Additional issues with binary JVS quantisation and trapped flux – experiments are proof of principle.

CCC signal and noise





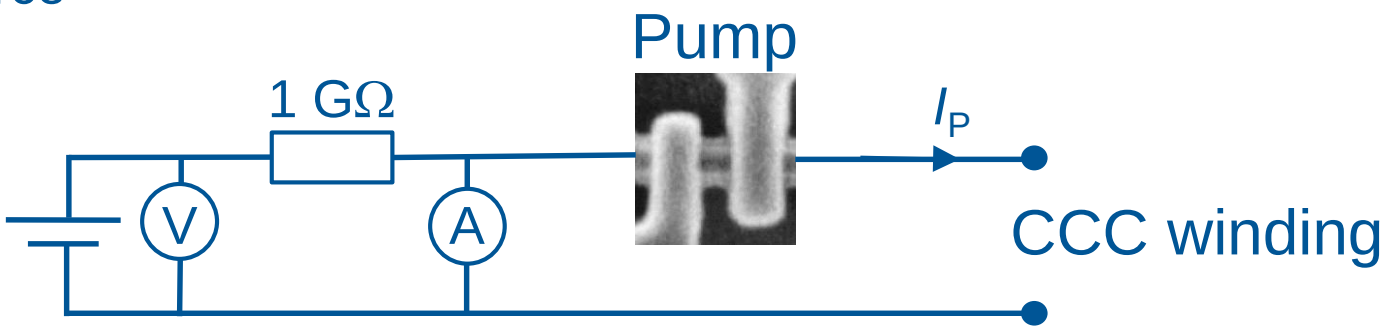
Full signal 320.4 pA
ΔV_S = 157.5 mV
$\Delta\Phi = 2.25\ \Phi_0$.

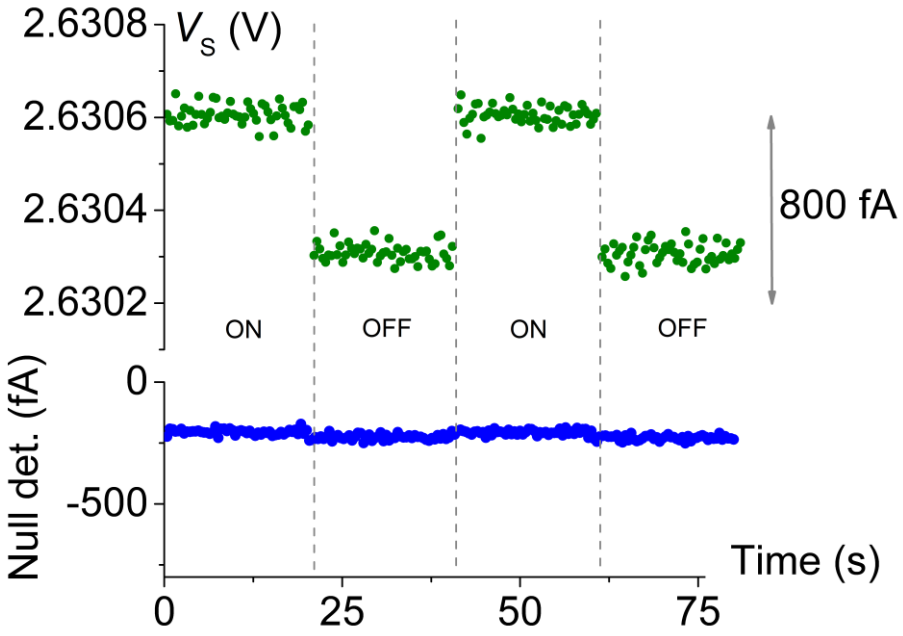
(0.1 ppm is 0.225 $\mu\Phi_0$)

Noise ≈12 fA / √Hz at 1 Hz
S/N ratio ≈ 38 ppm at 1 Hz

Full system – raw data

Measure pump current using CCC and conventional reference source

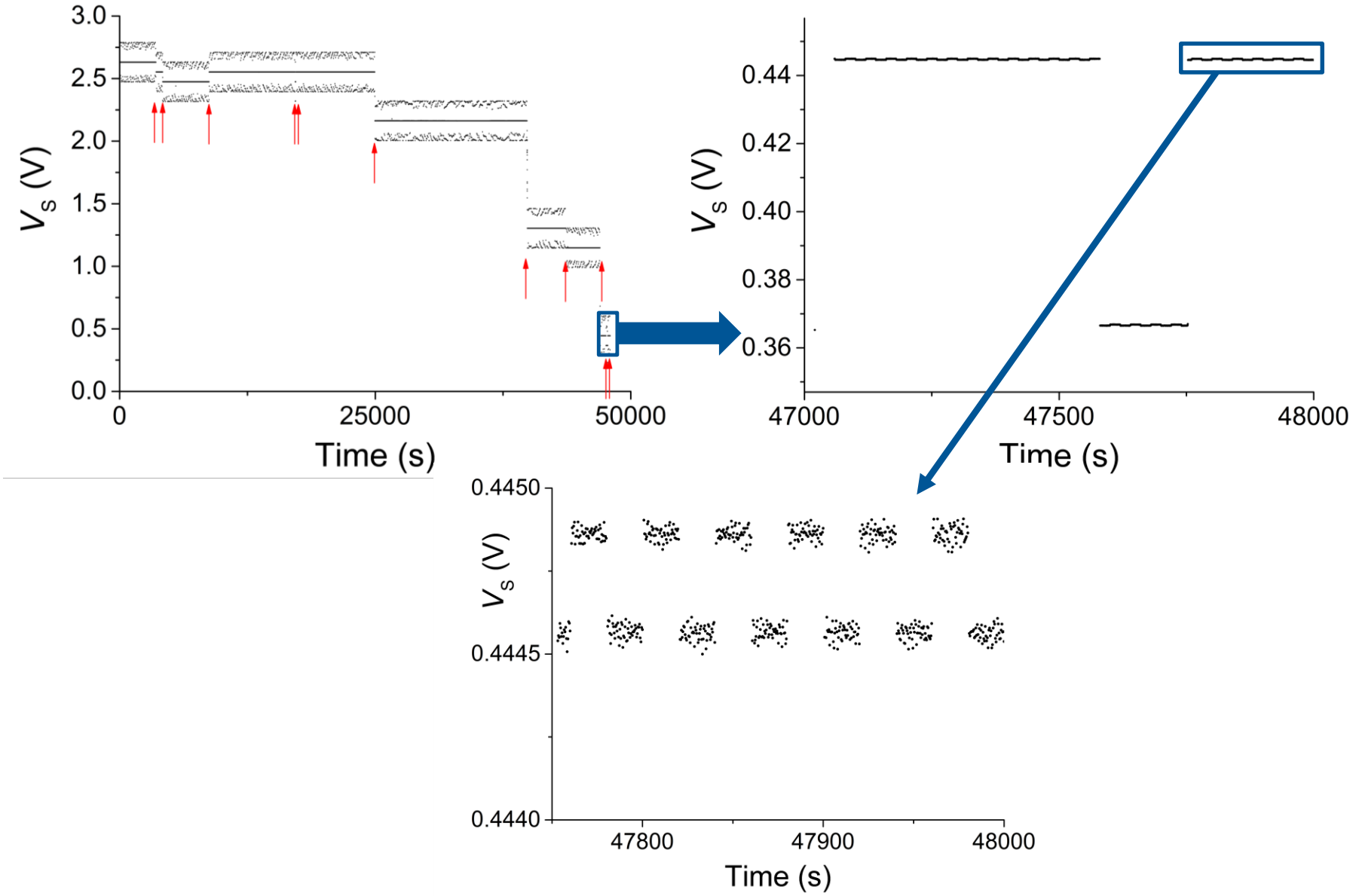




0.25 % of full signal
5.7 mΦ_0.

(Squid linearity was better than 0.01 %)

Stability over ≈13 hours



Result expressed as pump current

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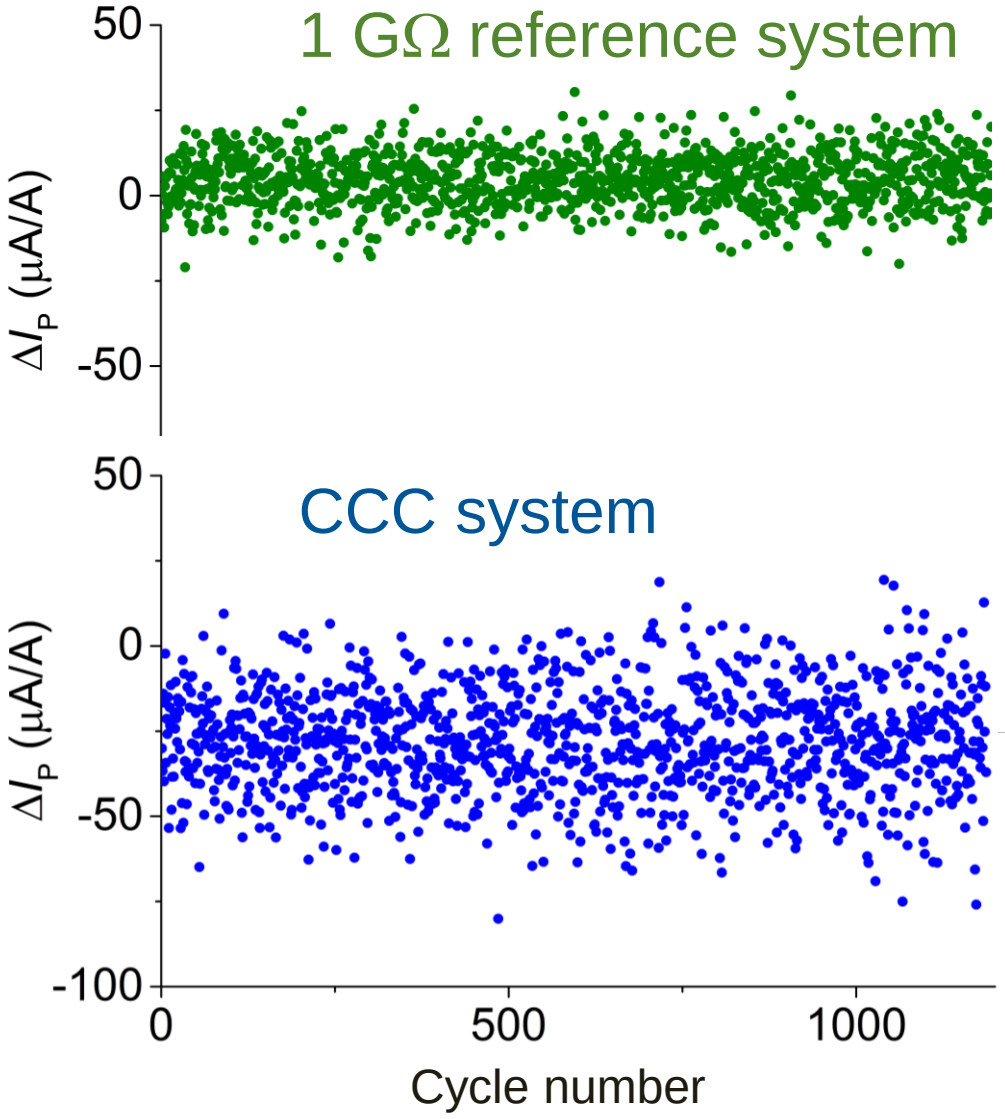
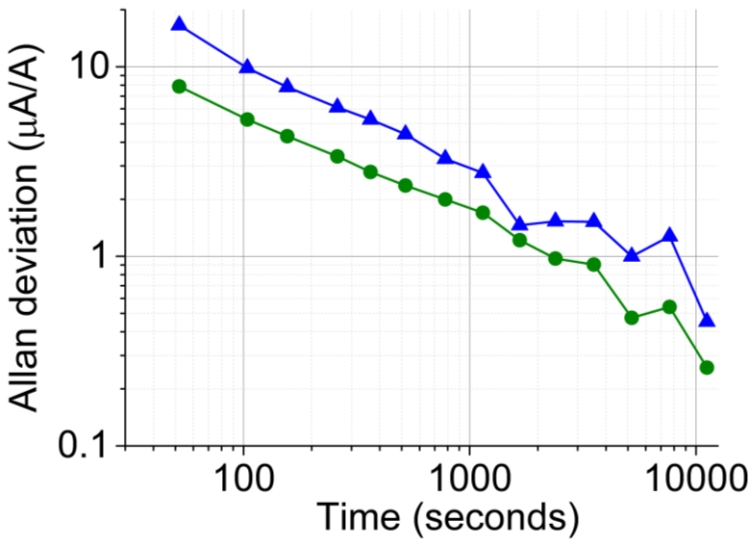


Mean ± SEM

4.7 ± 0.2



-28.1 ± 0.4

Conclusions

- First direct measurement of current from a tunable-barrier electron pump using a CCC
- We tried it....
- Some things worked – squid stability
- Some things didn’t work – JVS flux trapping

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Metrology ‘triangle’

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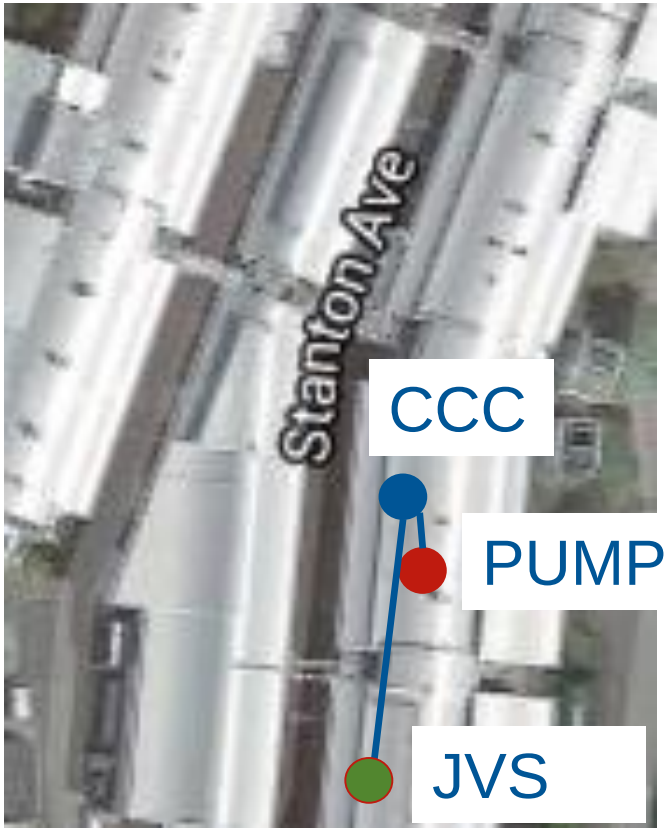
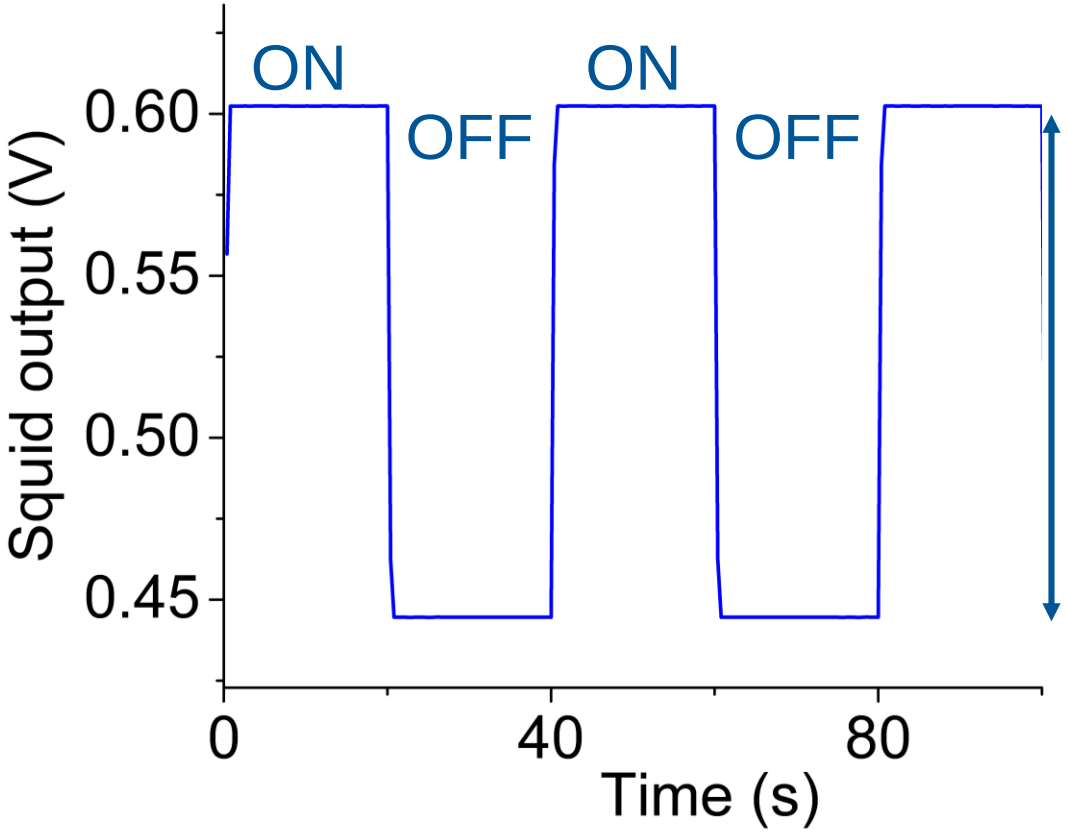


Pump current only

Use pump to calibrate sensitivity of CCC ≈ 6.4 μA turns / Φ_0



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