

Towards scaling-up single-electron currents: multiplexed operation of quantum-dot pumps with accelerated characterisation using machine learning

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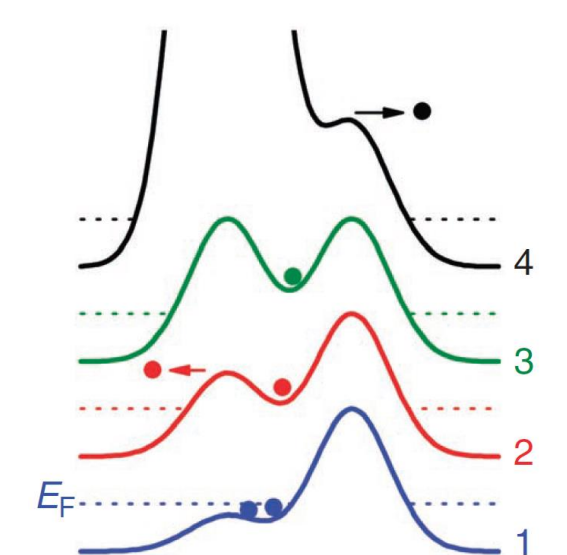
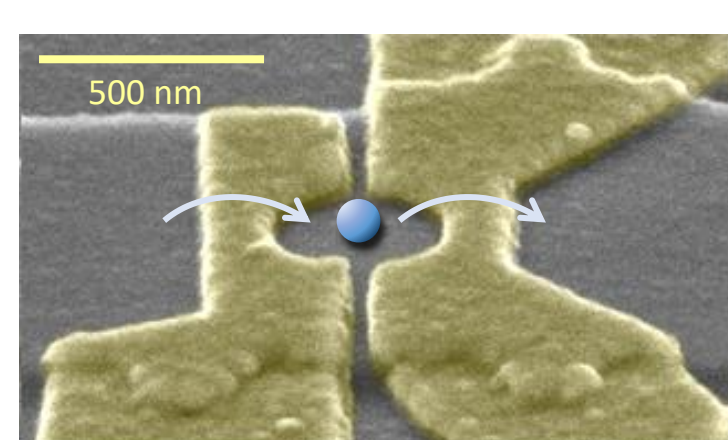
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Summary

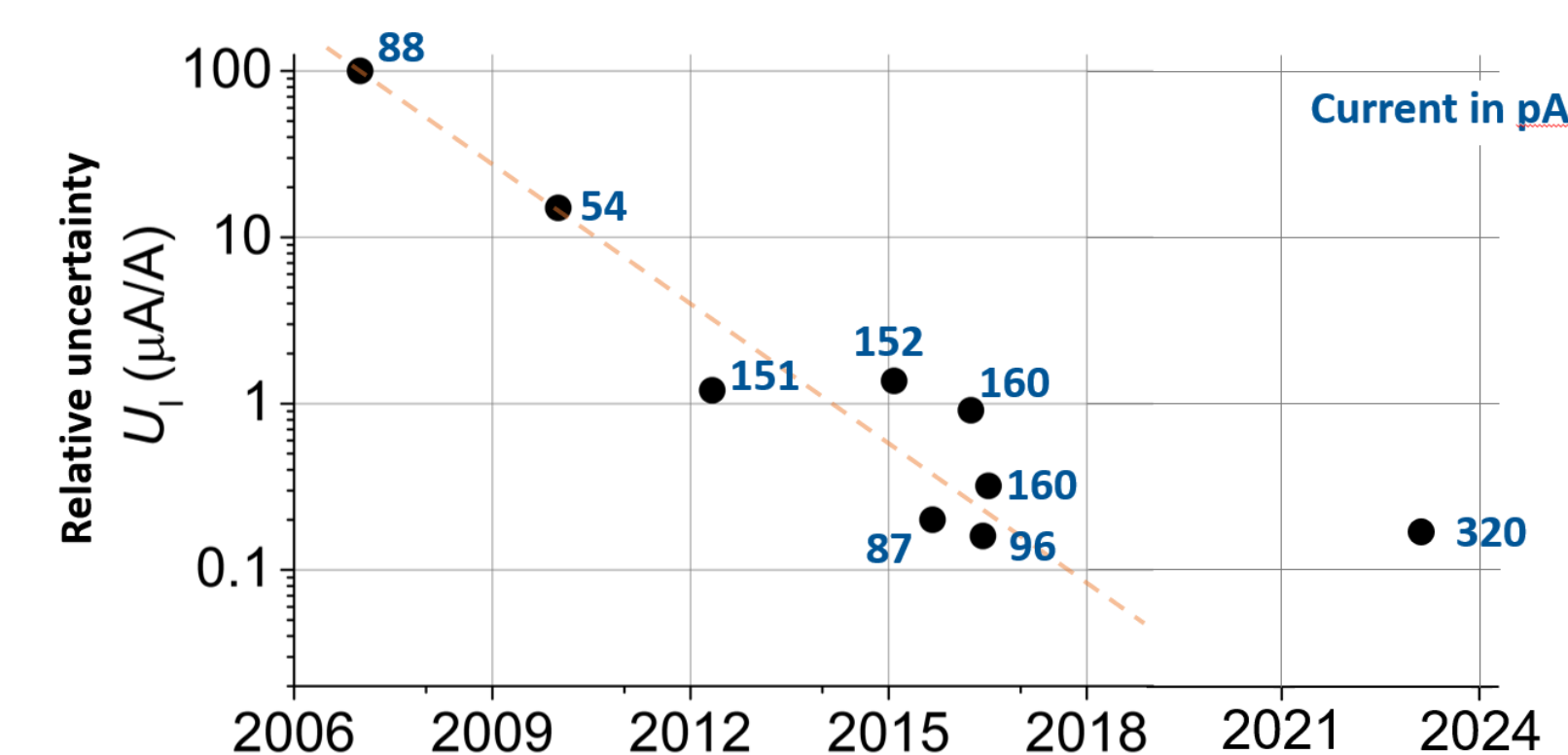
- We demonstrate the operation of multiplexed single-electron pumps up to 64 pumps on chip.
- The statistics of device operating parameters have been studied in one single cooldown of the chip.
- A method of pump parallelisation (up to three pumps) has been demonstrated using the multiplexer circuit.
- A machine learning technique has been developed to accelerate the pump characterisation process.
- These methods are expected to enhance the scalability of single-electron device technologies.

Single-electron pump



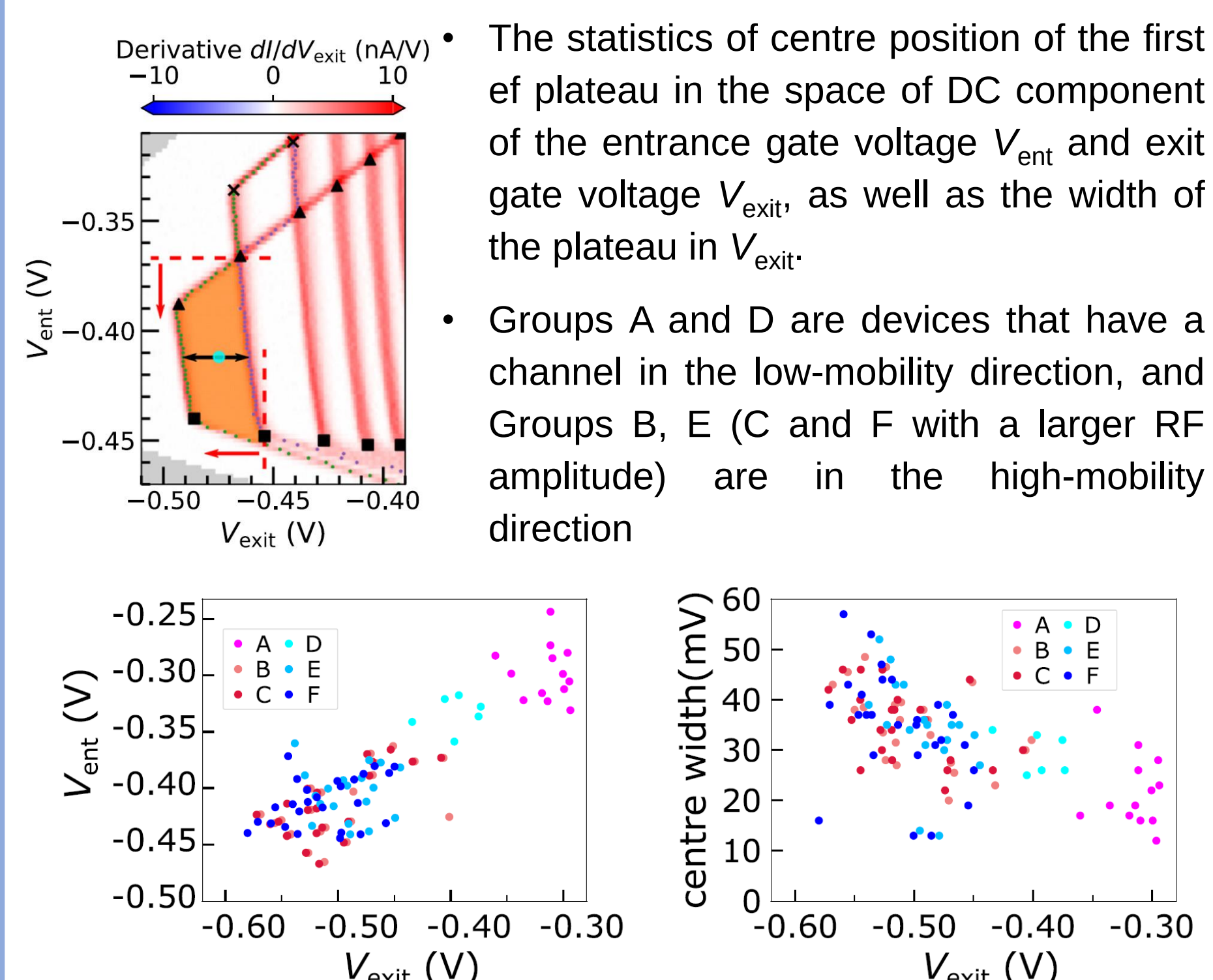
- A tunable-barrier quantum dot pump consists of a channel of two-dimensional electron gas, an entrance-barrier gate, and an exit-barrier gate.
- A radio-frequency drive on the entrance-barrier gate pumps electrons.
- The number of electrons pumped per cycle can be tuned by the voltage on the exit-barrier gate.
- With the elementary charge e and operation frequency f , the generated current is $I = \langle n \rangle e f$, where $\langle n \rangle$ is the average number of electrons pumped per cycle.
- With $f = 1$ GHz and $\langle n \rangle = 1$, $I \approx 160$ pA.
- The error rate of electron transfer is approaching 10^{-7} .

Electron pump accuracy

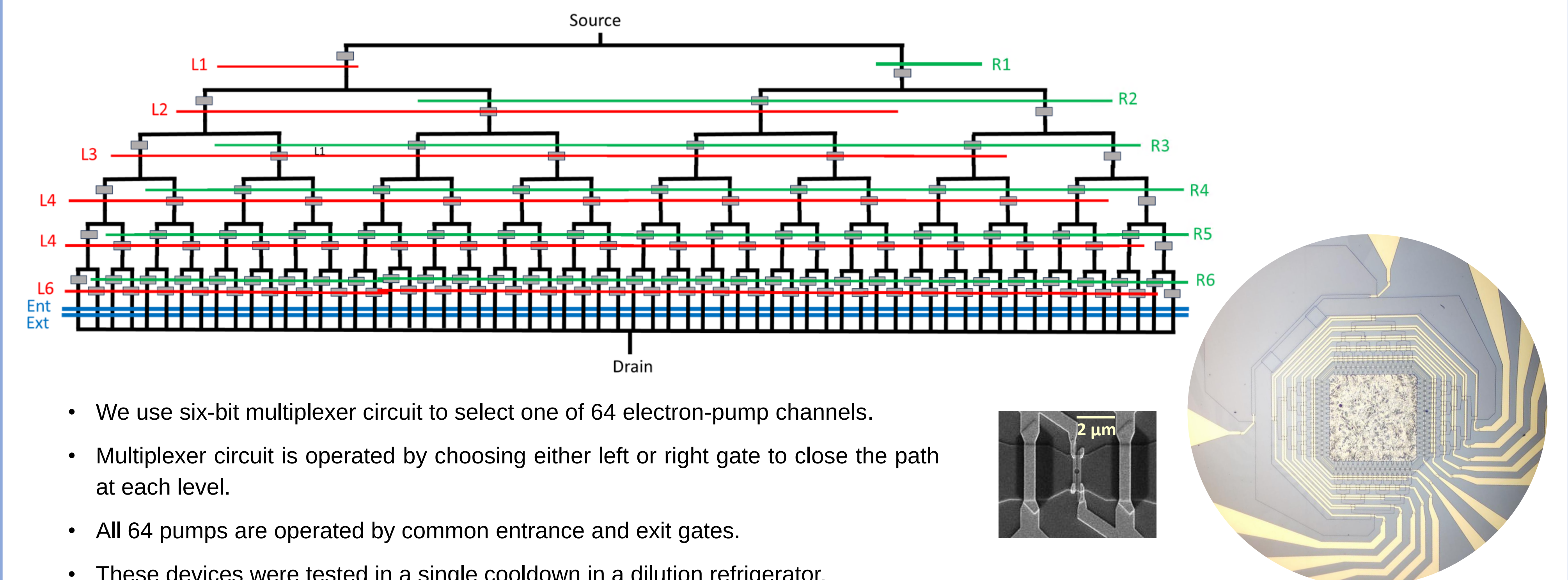


- Accuracy of electron-pump current has been tested by measurement traceable to the SI ampere.
- In the last one decade, the measurement accuracy seems to be hitting the 0.1 ppm barrier.
- Scaling up the electron pump current would eliminate this barrier.

Statistics

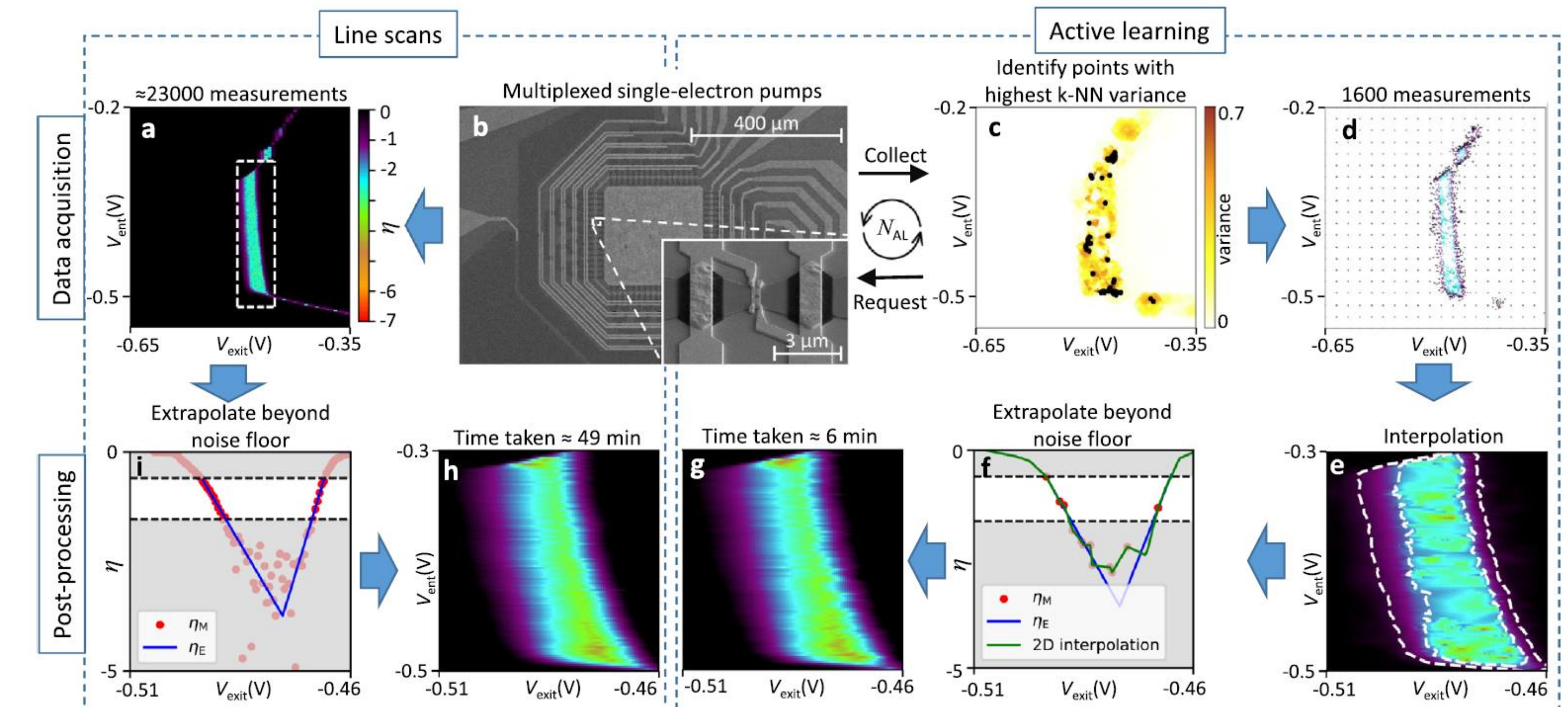


Multiplexer technology



- We use six-bit multiplexer circuit to select one of 64 electron-pump channels.
- Multiplexer circuit is operated by choosing either left or right gate to close the path at each level.
- All 64 pumps are operated by common entrance and exit gates.
- These devices were tested in a single cooldown in a dilution refrigerator.

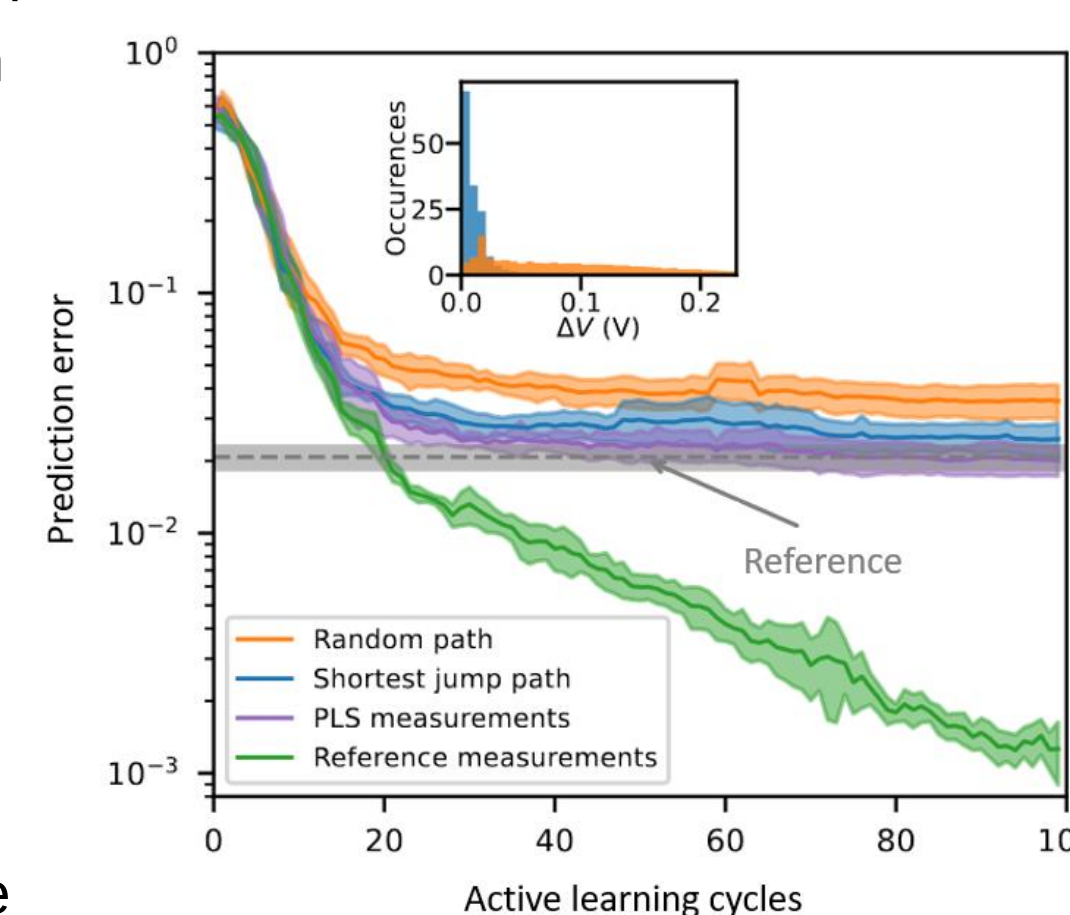
Automated characterisation with active learning



- For a scalable tuning of the single-electron pumps, we introduce an Active Learning Sparse Measurement (ALSM) framework.
- ALSM iteratively identifies the most informative measurement points in the voltage landscape with machine learning (based on the k-NN variance).
- Post-processed quantifications of the single-electron quantisation with an additional extrapolation beyond the noise floor of the measurement data.

Active learning speed up

- Systematic convergence of the ALSM characterisation to reach the target quality with about a **factor of ten** less measurements compared to conventional grid scans over the parameter space without manual input.
- Additional measurement fluctuations alleviated through optimisation of the measurement path.
- Fast and automated device tuning with machine learning paving the way for scaling up parallelised single-electron technology.



Conclusion and perspective

- Multiplexer technology is used to control a large number of single-electron pump devices on chip.
- Machine learning tuning provides a general blueprint for a fast and fully-automated screening of quantum devices with little manual input to overcome scalability barriers.
- Combining these two technologies will enable the scalability of single-electron pumps towards metrological applications.
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