# Ultra-Low-Noise Detector Technology for Donor-Qubit Architecture Engineering and High-Resolution RBS Analysis

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The remarkable success in addressing and manipulating single P-donor spins ("qubits") in $^{28}$Si [1,2] represents a milestone for the realisation of silicon-based quantum-computing. Inspired by these results, innovative P-donor quantum architectures were recently proposed [3]. Successful multi-qubit entanglement will depend on development of protocols that allow the engineering of well-defined shallow donor-qubit arrays. Furthermore, the elimination of disturbing background spins ("spin vacuum") via isotopic enrichment with $^{28}$Si is crucial to ensure a robust qubit-ensemble control.

The proposed new architectures pose new challenges for ion implantation. The challenges range from the deterministic engineering of ordered ultra-shallow donor arrays with nanometre precision, to ultra-high fluence implants (>$10^{18}$ cm$^{-2}$) for local isotopic $^{28}$Si purification with negligible impurity introduction.

With regard to the first challenge, our ongoing development of ultra-low-noise detector electronics has yielded a number of key achievements. We present single ion detection performance at room temperature for 14 keV $P^+$ ions and address the employment of heavy $PF_3^+$ molecule-ions to enable sufficient single ion detection fidelity of sub-10 keV ions. This ability constitutes a major step towards upscale-compatible donor-qubit placement with sub-10 nm spatial precision.

A modified configuration of this detector setup allows RBS measurements with an energy resolution below 5 keV for 1 MeV $He^+$ probe ions. We apply this technique to monitor the isotopic enrichment and impurity introduction in silicon for $^{28}Si^+$ and $^{28}Si^-$ implant fluences above ~4 ×$10^{17}$ cm$^{-2}$.

[1] J. Pla et al., Nature 489, pp. 541-545 (2012)
[2] J. Pla et al., Nature 496 (2013)
[3] G. Tosi et al., Nat. Commun. 8, 450 (2017)