

In situ detection of single ions implanted in diamond



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1. Introduction

Quantum computers offer possibilities unparalleled by their classical counterpart. Solving problems that would take hundreds of years on a classical computer, could be done on a quantum computer in a matter of seconds, whereas quantum sensors with their high sensitivity and low dimensions enable us to do measurements with extreme precision. The most promising materials for realization of both quantum computers and quantum sensors are certainly silicon and diamond. Diamond is especially interesting because of NV (nitrogen vacancy) center, stable at room temperature. Deterministic single ion implantation – a state-of-the-art technique already used for silicon, has yet to be demonstrated for diamond. Proposed research is focused on understanding the crucial parameters needed for successful detection of shallow low energy ions in diamond. The aim is to achieve a detector architecture suitable for deterministic single ion implantation in diamond.

2. Methodology

Diamond detector was irradiated with focused ion beams of different energies and ion species in IBIC (ion beam induced charge) mode. The signal induced in diamond by impinging ions was amplified and recorded in real time. The charge collection efficiency (CCE), the parameter defined as the ratio between the charge detected by the preamplifier and the total charge induced by impinging ions was calculated. All irradiations were done at the Laboratory for Ion Beam Interactions at Ruđer Bošković Institute.

CCE increases as the penetration depth decreases – maximum for 100 keV protons.

Sudden drop in CCE in case of Cu ions due to interaction with electrode material. Penetration depth is of the same order of magnitude as the electrode thickness.

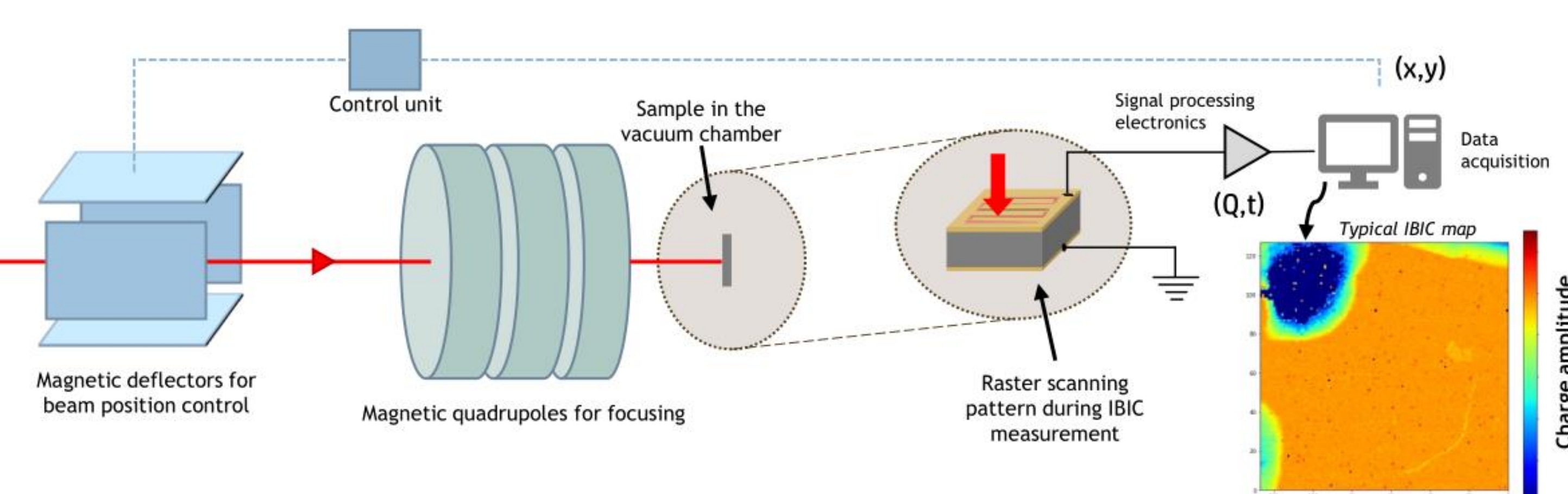


Illustration of IBIC setup at Ruđer Bošković Institute

Only two strip electrodes were used in the measurements with the electric field between them. This configuration was chosen to investigate whether the area between the strips can be used as implantation site.

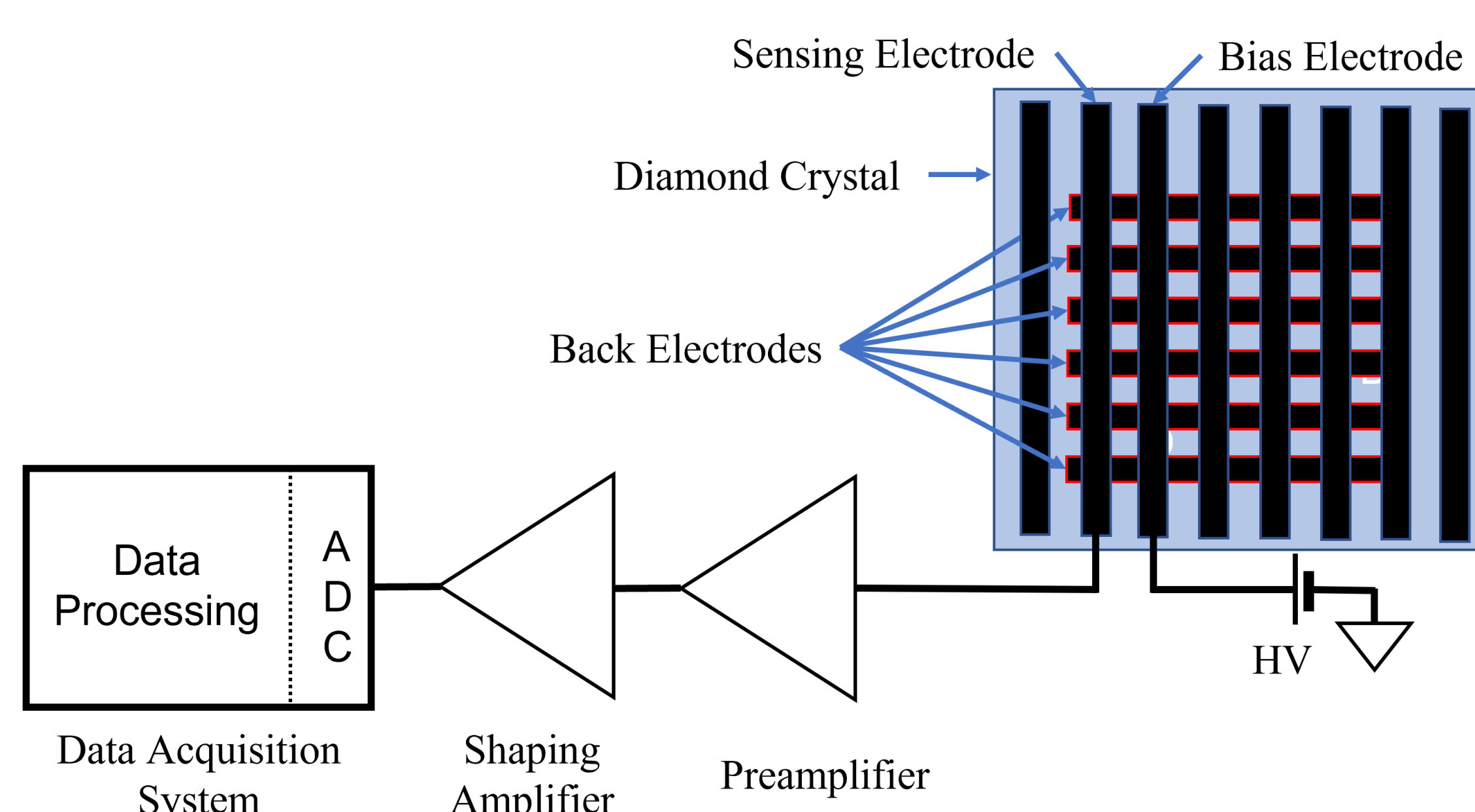
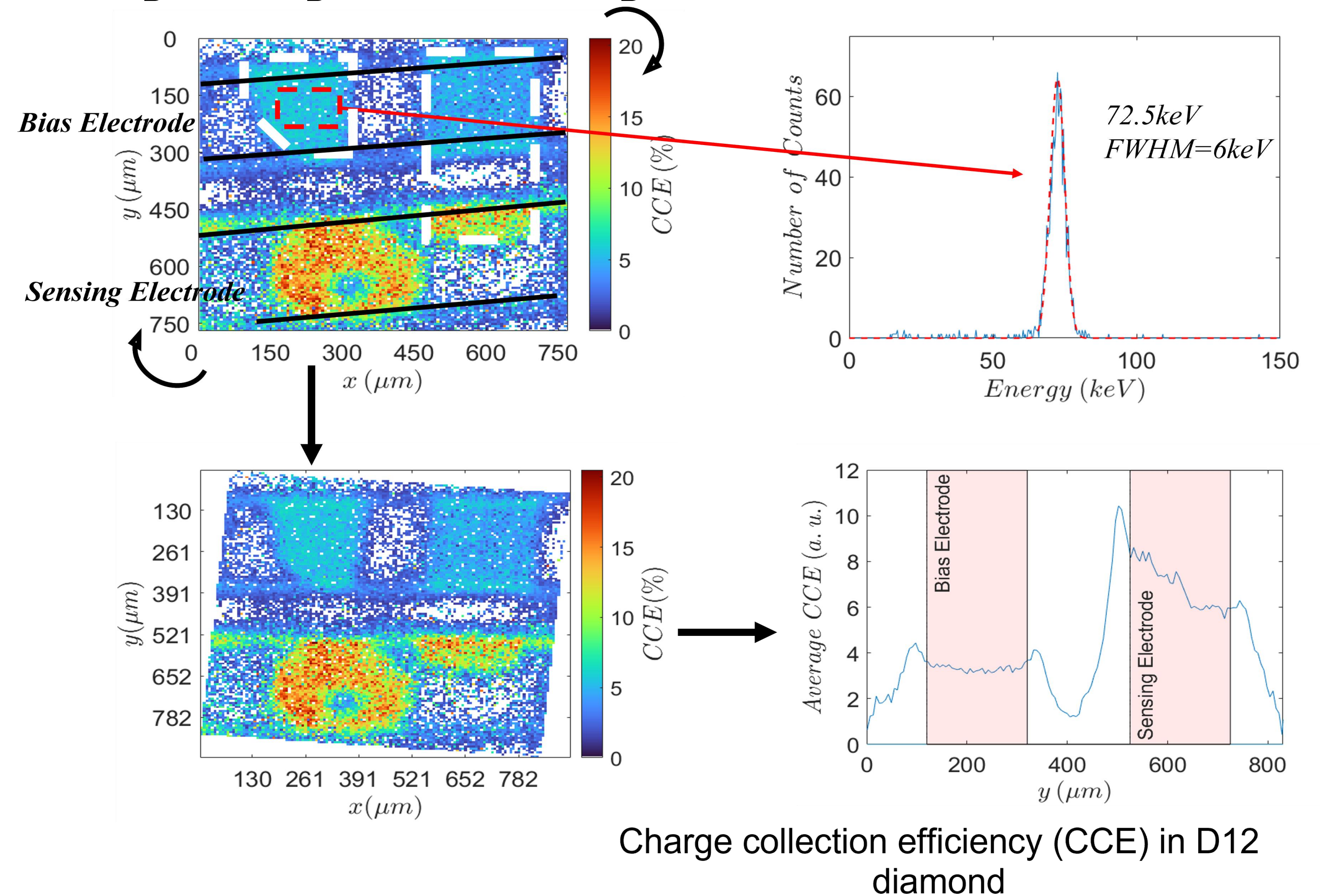


Illustration of the detector and read-out electronics setup

3. Results

CCE maps were analyzed and the energy resolution, represented by full width at half maximum (FWHM) of a monoenergetic peak, was extracted. The figure below shows an example of a CCE map obtained by 1 MeV protons, and a monoenergetic peak extracted from the map. It also shows the projection of CCE on the y-axis with the electrode positions shaded. It shows that the highest CCE is along the edge of the sensing electrode.



Charge collection efficiency (CCE) in D12 diamond

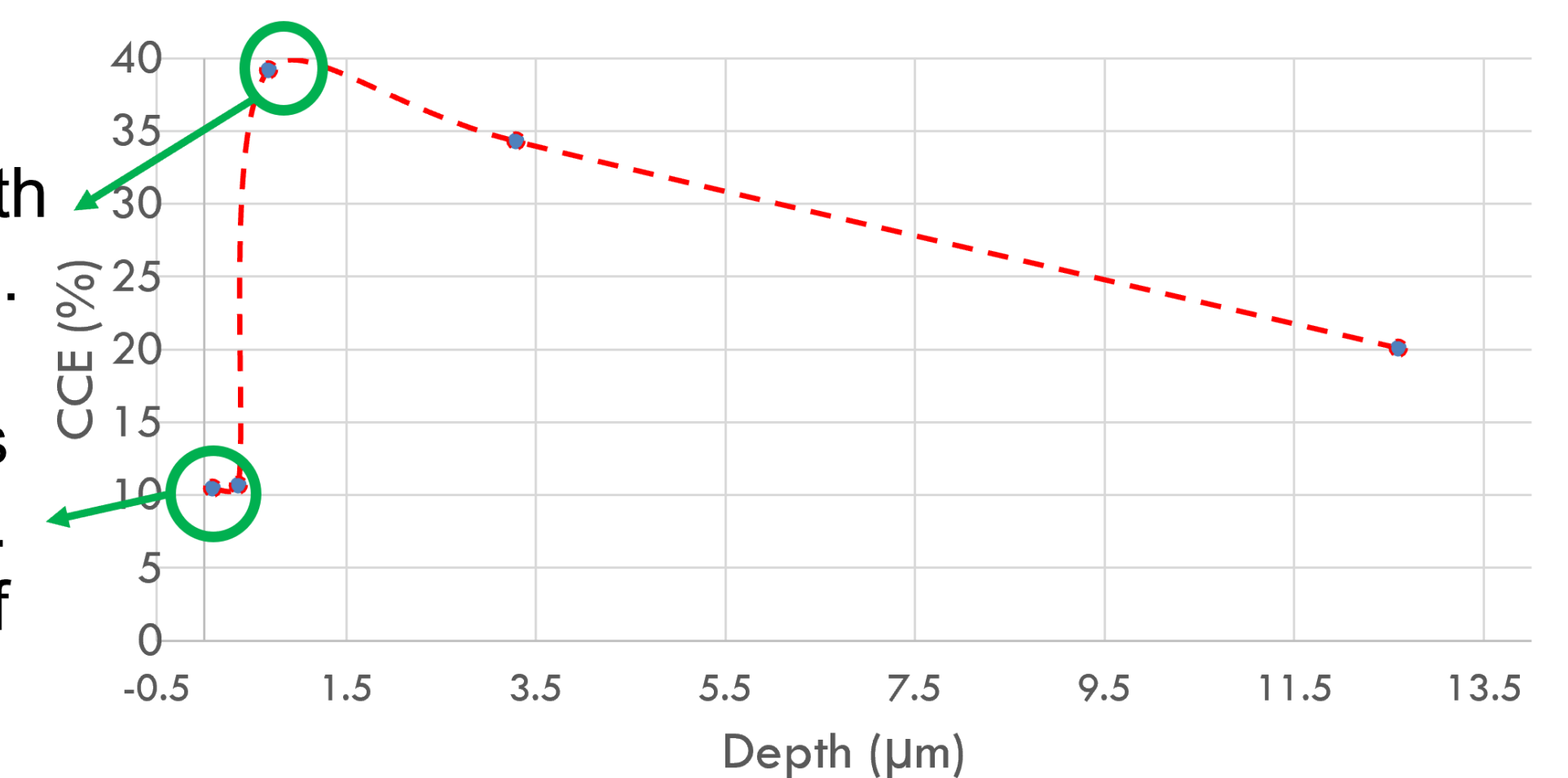


Table showing penetration depths and the highest recorded CCE for each of the ion beams used in the measurements.

Ion	Energy	Average penetration depth	Highest recorded CCE
H^+	1000 keV	12.6 μm	20.5%
H^+	400 keV	3.3 μm	35%
H^+	100 keV	0.7 μm	40%
Cu^{2+}	140 keV	0.1 μm	10.7%

4. Conclusion

The main result is successful detection of 140 keV copper ions which penetrate on average only 100 nm in diamond. Also, the achieved energy resolution of 6 keV enables detection of even lower energies. However, the recorded CCE is quite low, especially for 140 keV Cu ions. Other electrode geometries which would enable higher electric fields and thus higher CCE should be investigated.

5. Project Acknowledgement

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