The complexity and variety of molecules offer opportunities for metrology and quantum information that go beyond what is possible with atomic systems. The hydrogen molecular ion is the simplest of all molecules and can thus be calculated ab initio to very high precision [1]. Combined with spectroscopy this allows to determine fundamental constants and test fundamental theory at record precision [2–4]. Spectroscopy of H^+_2 should improve substantially by performing experiments with single hydrogen molecular ions, reducing systematic uncertainties and improving signal strength. This necessitates quantum control.

I will present our progress towards full quantum control of a single hydrogen molecular ion. Our most recent results demonstrate the co-trapping and cooling of single H^+_2 and $^9Be^+$ ions. The experimental apparatus features a cryogenic ultra-high vacuum chamber, housing a micro-fabricated monolithic linear Paul trap. H^+_2 is loaded into the trap by electron bombardment of H_2. We aim to use He buffer gas cooling in combination with quantum logic spectroscopy to initialize the internal state of H^+_2 in a pure quantum state and implement non-destructive readout [5-9].

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