QSNET: Towards a Californium Highly Charged Ion Clock

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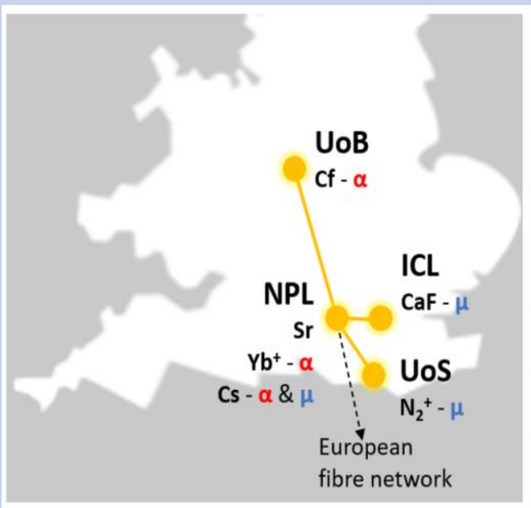
- **QSNET** is searching for variations of fundamental constant.
- **A unique network of clocks** chosen for their different sensitivities to variations of **fine structure constant**, **α**, and the **electron-to-proton mass ratio μ**.
- The clocks will be **linked with dark fibres**, essential to do clock-clock comparisons.
- With a range of clocks at **different technology readiness levels**, we are **achieving world-leading results** and will deliver increasingly competitive outcomes as advanced clocks go online.
- At **Birmingham**, we are aiming to build a **Californium highly charged ion (HCI) clock** and to search for the variation of **α**.

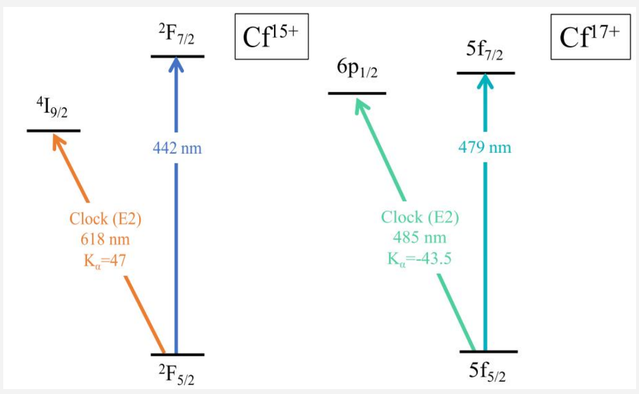


Clock	Kα	Kμ
Yb^+ (467 nm)	-5.95	0
Sr (698 nm)	0.06	0
Cs (32.6 mm)	2.83	1
CaF (17 μm)	0	0.5
N_2^+ (2.31 μm)	0	0.5
Cf^{15+} (618 nm)	47	0
Cf^{17+} (485 nm)	-43.5	0

In the table, we report the wavelength of the clock transitions and the sensitivity coefficients K_α and K_μ [1].

Why Californium HCI Clocks?

HCIs are highly sensitive to variations in α due to strong relativistic effects and are less affected by external perturbations due to their compact electronic cloud.

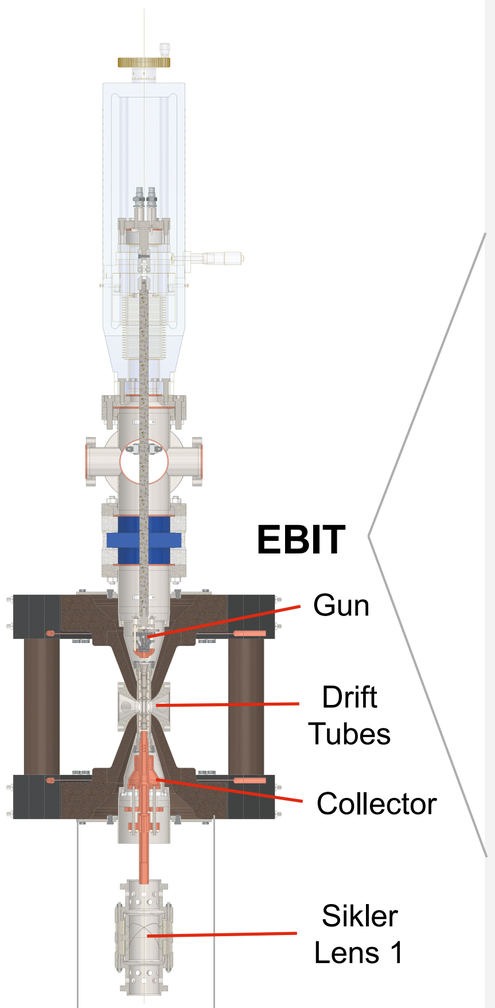


Cf^{15+} and Cf^{17+} features:

- Optical transitions.
- Excited-state lifetimes between 1 and 10^4 seconds.
- Strong transitions for cooling and detection.
- Clock levels cancel various systematic shifts.

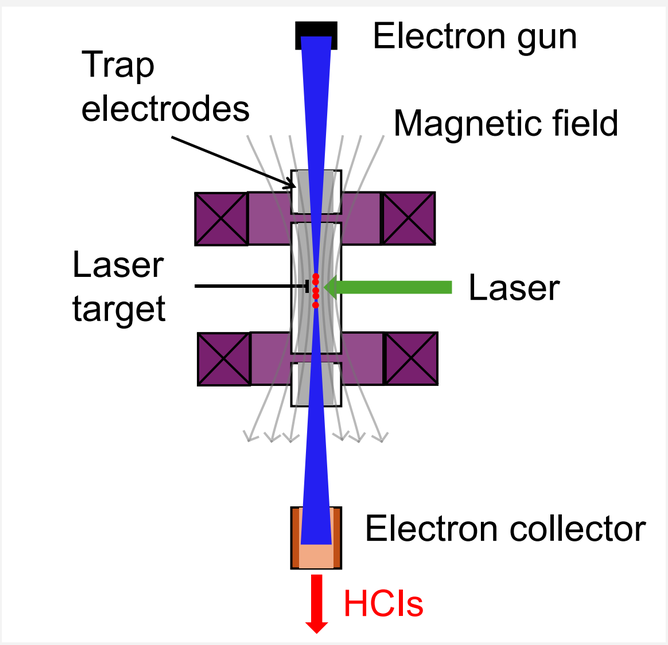
Dual Clock Benefits:

- Co-trapping Cf^{15+} and Cf^{17+} cancels residual common systematic effects due to opposite K coefficients.



How does the EBIT work?

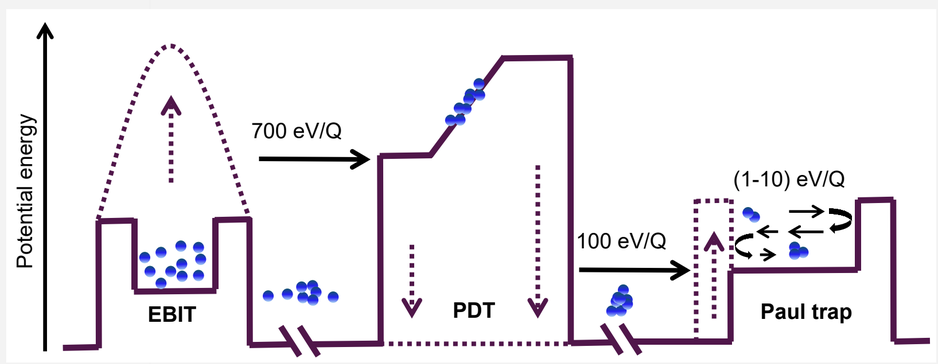
- Laser ablation source for Cf injection.
- EBIT for reaching high charge states. Elelctron impact ionization:
  $X^{q+} + e^- \rightarrow X^{(q+1)+} + e^- + e^-$

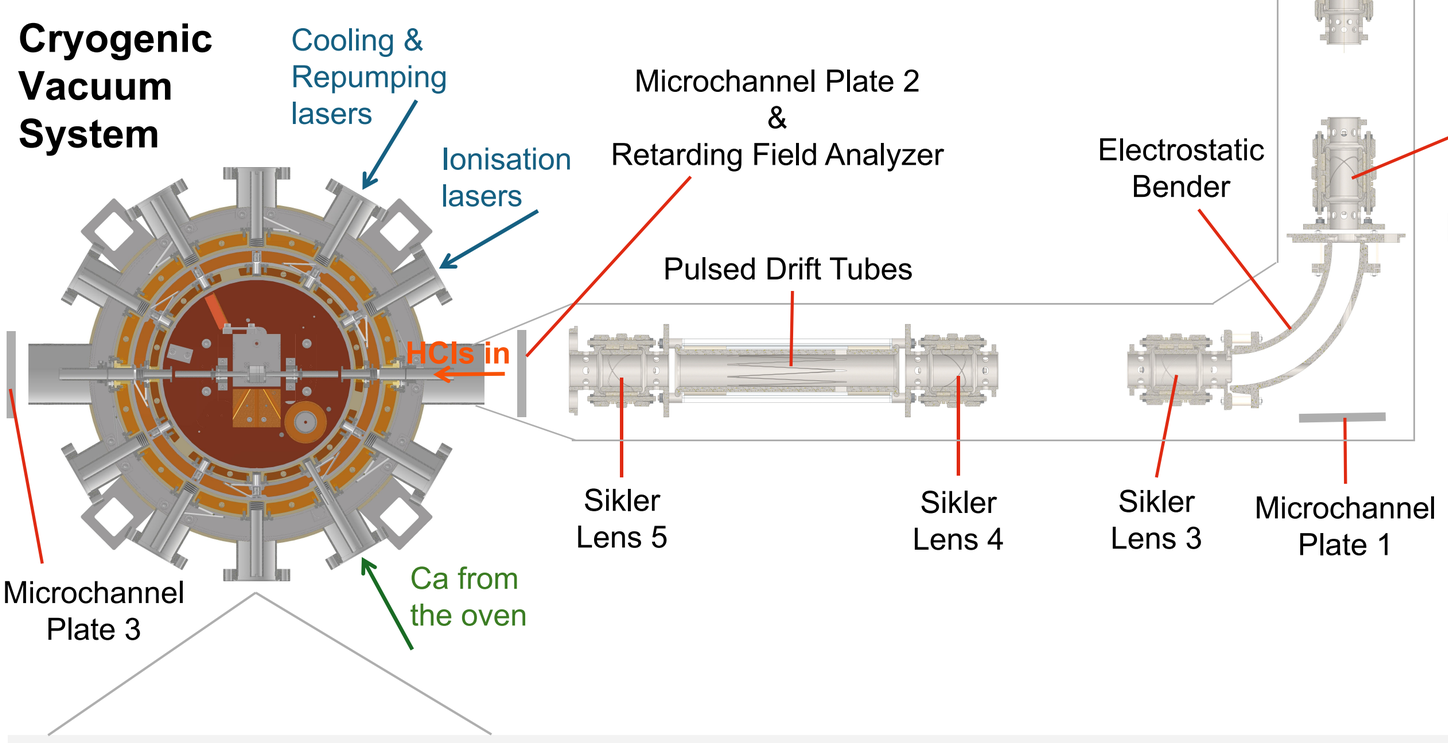


In collaboration with MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

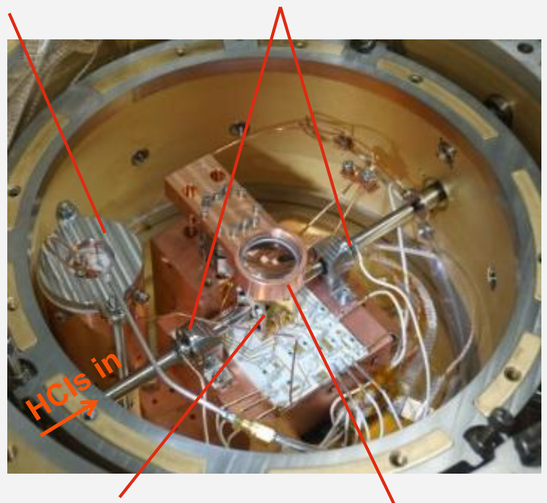
How does the Beam-line work?

- Beam-line for transferring ions to spectroscopy trap and charge state selection.

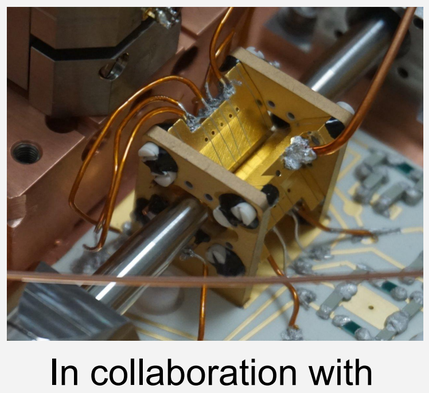




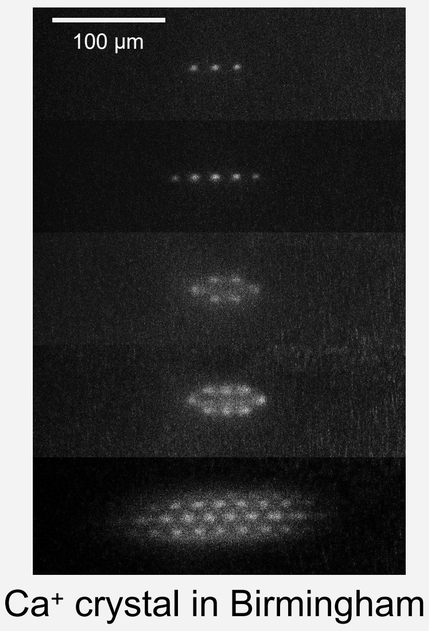
Beam-line



Cryogenic Paul trap:



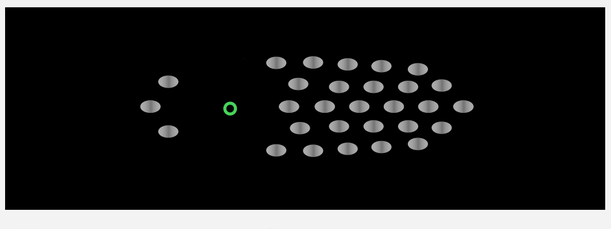
In collaboration with PTB



Ca^+ crystal in Birmingham

Next Steps

- Once produced and pre-cooled, the ions are implanted into a Coulomb crystal of singly-charged Ca^+ ions.
- Sympathetic cooling with the crystal.



Example: an HCI cooled in a crystal.

- Quantum Logic Spectroscopy using the co-trapped ions [2].

References
[1] Barontini *et al.,* Measuring the stability of fundamental constants with a network of clocks, *EPJ Quantum Technol.* **9**, 12 (2022)
[2] Micke *et al.*, *Coherent laser spectroscopy of highly charged ions using quantum logic,* Nature **578**, 60 (2020)