Highly charged ion production and their use in nuclear spectroscopy and mass precision measurements

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TITAN Facility

Highly Charged Ions (HCIs) enable the spectroscopical study of suppressed or even energetically forbidden decays in neutral atoms. Combined with Penning trap mass spectrometry, the HCIs can improve their precision and resolution to investigate physics beyond the Standard Model (BSM).

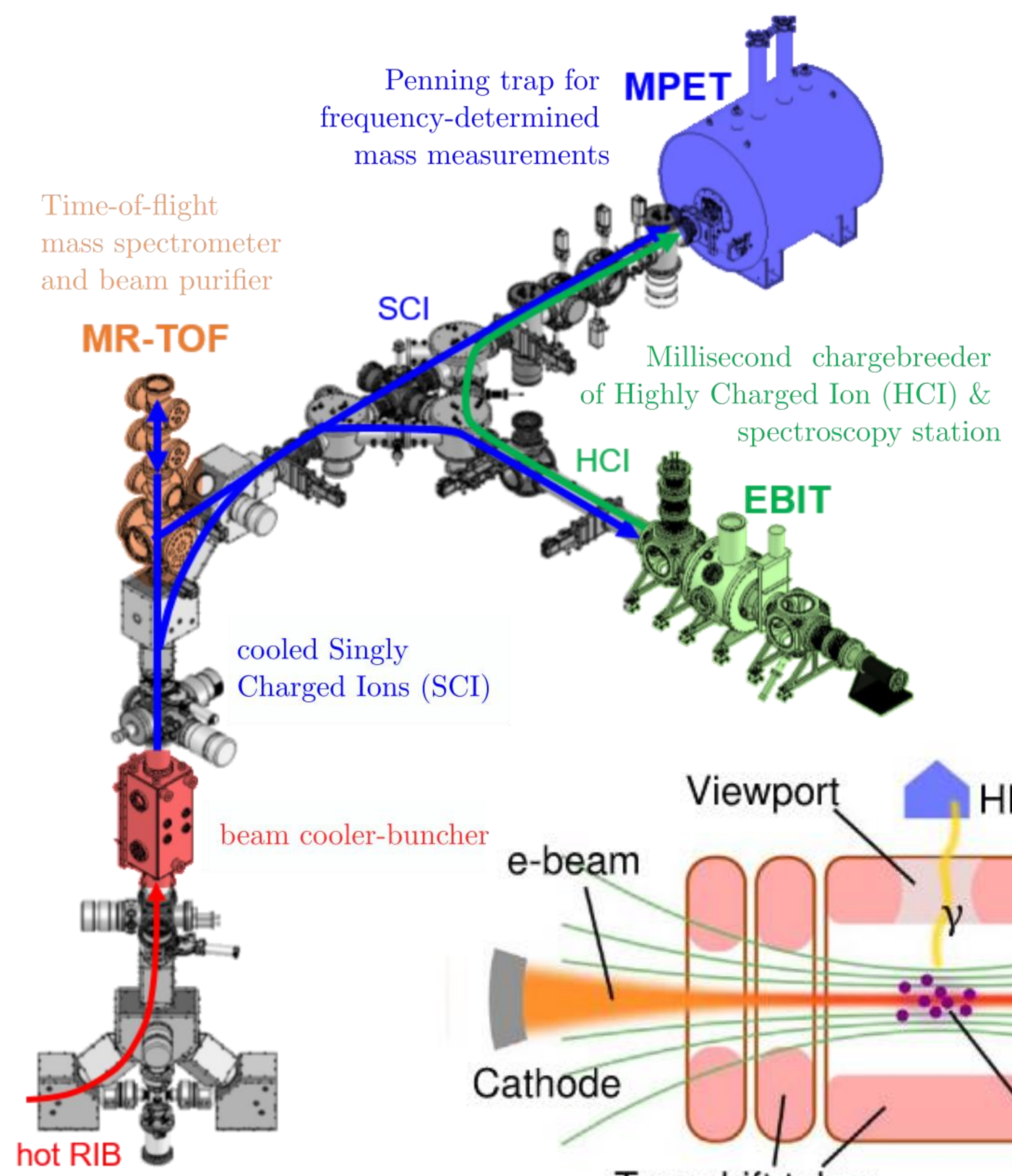
To achieve this, TITAN includes an Electron Beam Ion Trap (EBIT) to charge breed from radioactive Singly Charged Ions (SCIs) to radioactive HCIs for further study.

At TITAN, a beam cooler buncher prepares the ion beam for charge breeding and a Multi Reflection Time-Of-Flight spectrometer can optionally purify the beam to prevent charge breeding unwanted species.

The Measuring PEnning Trap (MPET) uses highly charged ion to reduce the mass measurement uncertainty dm/m~1/q, where q is the charge state.

The EBIT not only generates the HCI ions required for MPET but also stores them for in-situ spectroscopical studies. For example, a new Extreme Ultra-Violet (EUV) spectrometer to probe the nuclear charge of HCI will allow testing physics BSM [see Y. Wang poster #43].

TITAN focuses on high-precision, high-accuracy mass spectrometry as well as atomic and nuclear spectroscopy with ion traps.

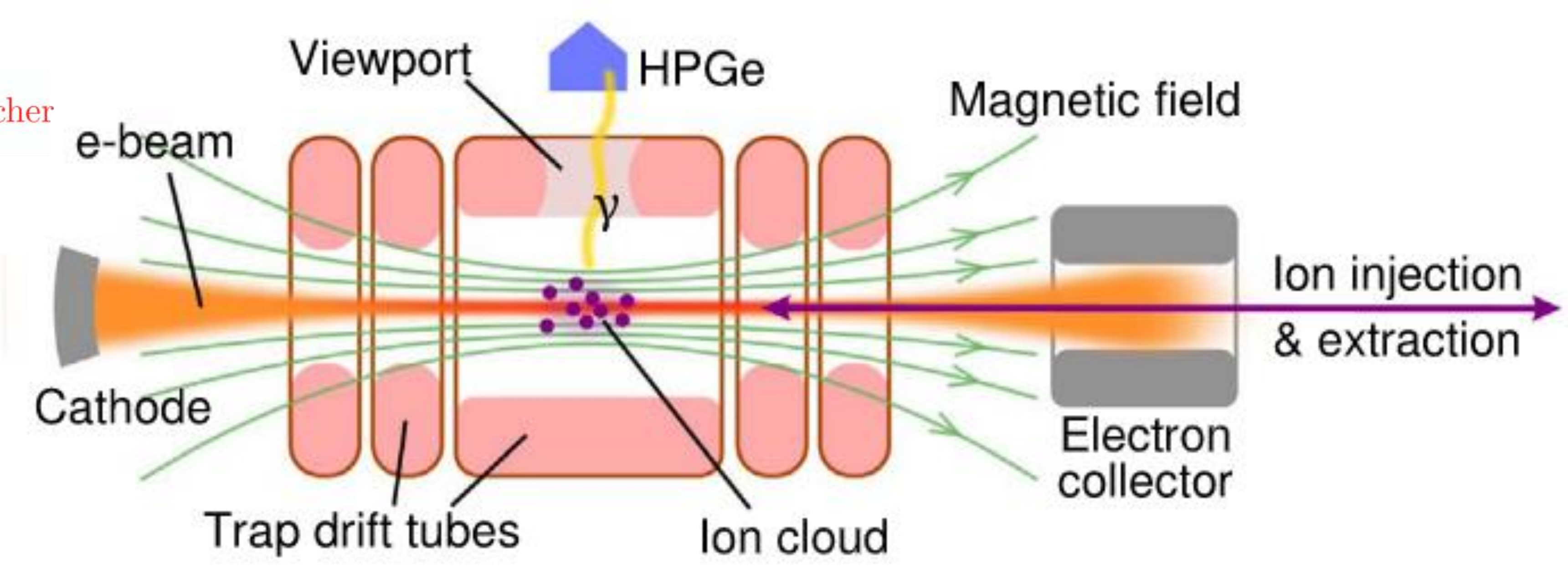


EBIT working principles

The EBIT consists of an electron beam, a set of electrostatics drift tubes, a collector, and a semi-Helmholtz coil.

The electron gun produces a beam of high-energy electrons which is compressed by the magnetic field, passes through the ion trap, and lands on the collector. The drift tubes generate an axial trapping potential that confines the SCI into an overlapping region with the electrons. An additional radial force develops due to the space charge of the electrons, creating more ion confinement.

Seven radial Be windows provide optical access to the trapped ions. Two suites of auxiliary detectors can be used either for science experiments or to monitor the charge breeding.



EBIT schematic showing the principle of operation.

TITAN HCI program

As the only Penning trap mass spectrometer with both RIB and HCI, TITAN is uniquely positioned to benefit from HCI to improve precision [1] to purify beam [2], and to create non-ISOL species [3].

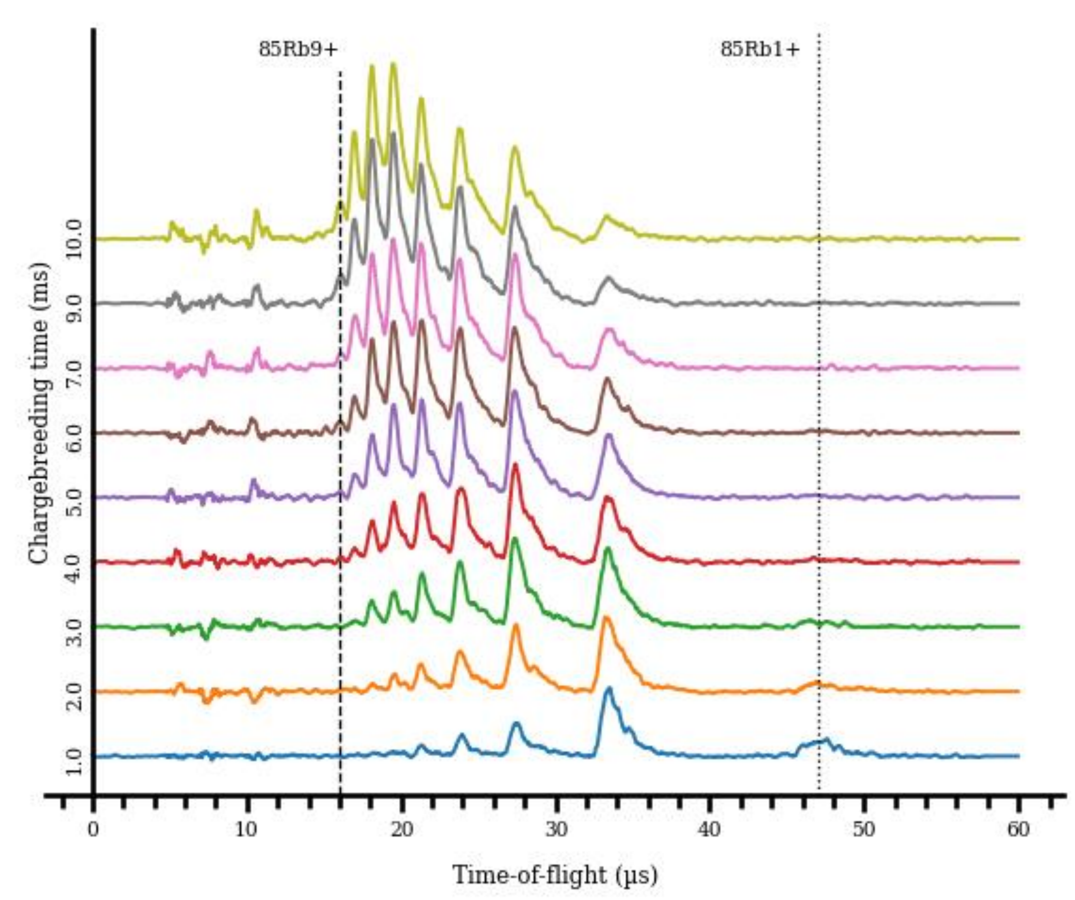
The EBIT's backing-free nature enables tape-independent and HCI-compatible in-trap spectroscopy. HCI allows for nuclear excitation by electron capture (**NEEC**), bound state beta decay, and orbital electron capture blocking, which are important in nuclear physics and nucleosynthesis.

By creating theoretically accessible H-, Li-, and Na-like electronic structures , absolute nuclear charge radii determination is possible. TITAN's combination of RIB, EBIT, and a forthcoming EUV spectrometer, enables unprecedented studies of nuclear structure and measurements of candidates for electron's electric dipole moment [see Y. Wang poster #43].

Selected results

Specific mass-over-charge are required for MPET and, depending on the nuclear species, fast charge breeding is mandatory.

The EBIT charge breeding capabilities have recently been demonstrated by injecting an external 85Rb ion beam, and different charge breeding times at different electron currents exhibit different charge state populations.

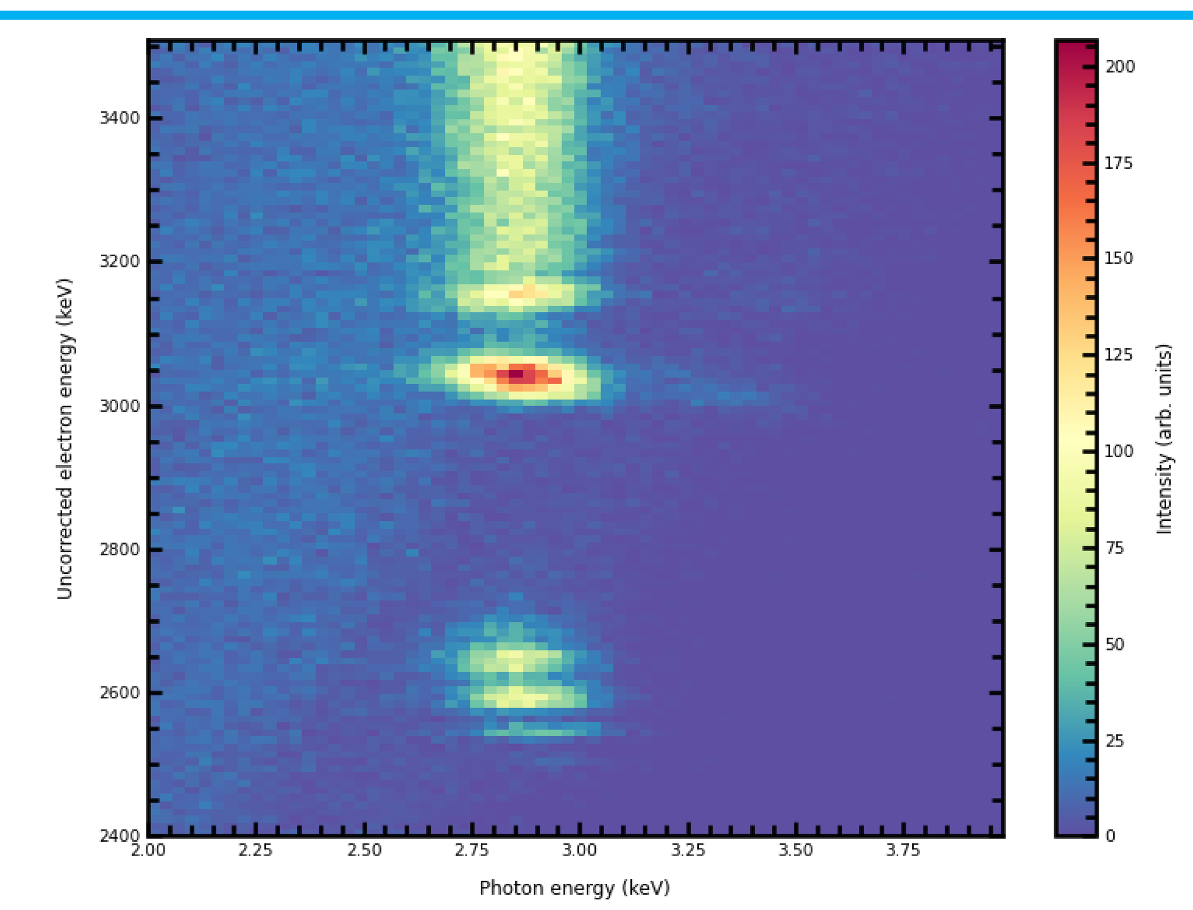


HCI spectrum for the same electron current (100 mA). By increasing the breeding time, higher charge states are populated. In this case, 85Rb9+ is achieved as of 5 ms.

Producing and storing HCIs becomes crucial for spectroscopy studies that require high statistics.

With the injection of neutral argon gas, the EBIT has demonstrated the capability to produce *charge states ~14+,* while storing them for about 1 minute. Due to the interaction of the intense electron beam with the HCI, measurements of the radiative decay by means of X-ray spectroscopy are possible.

Finally, due to recent electron-source repairs and HV upgrades, we are reestablishing EBIT operations. So far**, 500 mA at 7.1 keV electron energy has been achieved**. More studies are planned in preparation for the NEEC experiment this fall.



40Ar(14+-10+) X-ray spectrum. By varying the electron energy, a dielectric resonant process and its associated X-rays can be accessed for each charge state.

- ✓ **A revitalized EBIT enables the continuation of the high-impact HCI program at TITAN.**
- ✓ **HCIs from stable elements have been produced and study at TITAN by means of time-of-flight and x-ray spectroscopy.**
- ✓ **The TITAN EBIT displays a promising state for performing the NEEC experiment this upcoming fall.**

[1] S. Ettenauer PRL 2011 (Rb-74),
[2] M.C. Simon RSI 2013.
[3] E. Leistenschneider JPG 2020.

Discovery, accelerated