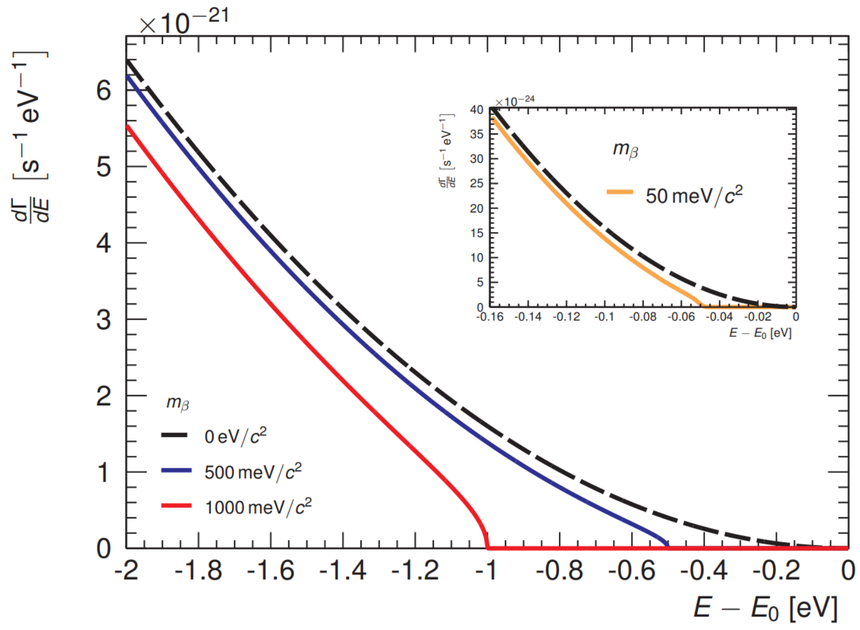
QTNM

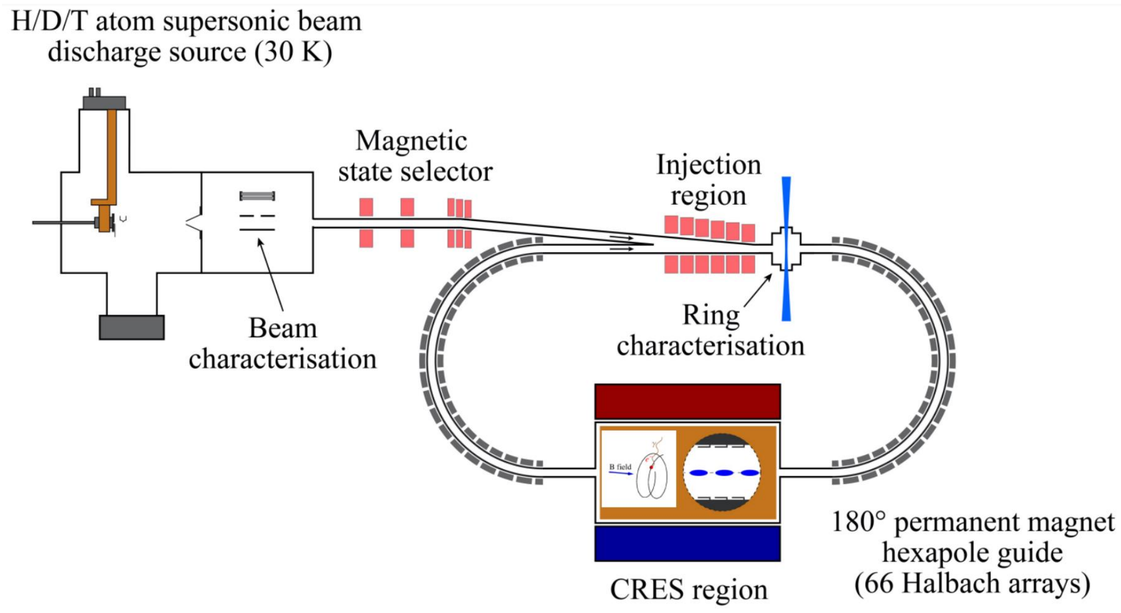
Quantum Technologies for Neutrino Mass

Determination of the Absolute Neutrino Mass with Quantum Technologies

Daniel Swinnock (on behalf of the QTNM Collaboration)

Quantum Technologies for Neutrino Mass (QTNM) is a project to investigate methods for measuring the absolute neutrino mass via Cyclotron Radiation Emission Spectroscopy (CRES) of electrons produced from the beta decay of atomic tritium.

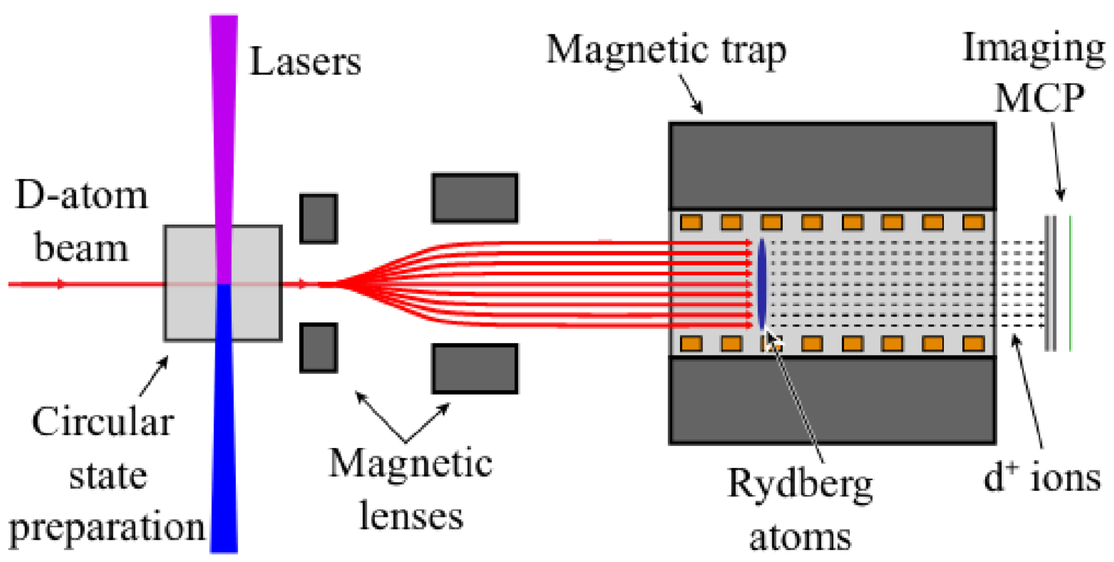




Cyclotron Radiation Emission Spectroscopy (CRES) is a method for measuring the kinetic energy of an electron undergoing cyclotron motion in a magnetic field. The frequency of the radiation is directly linked to the magnetic field and kinetic energy of the electron by

$$\Omega_c = \frac{eB}{\gamma m_e} = \frac{eB}{m_e + K_e/c^2}.$$

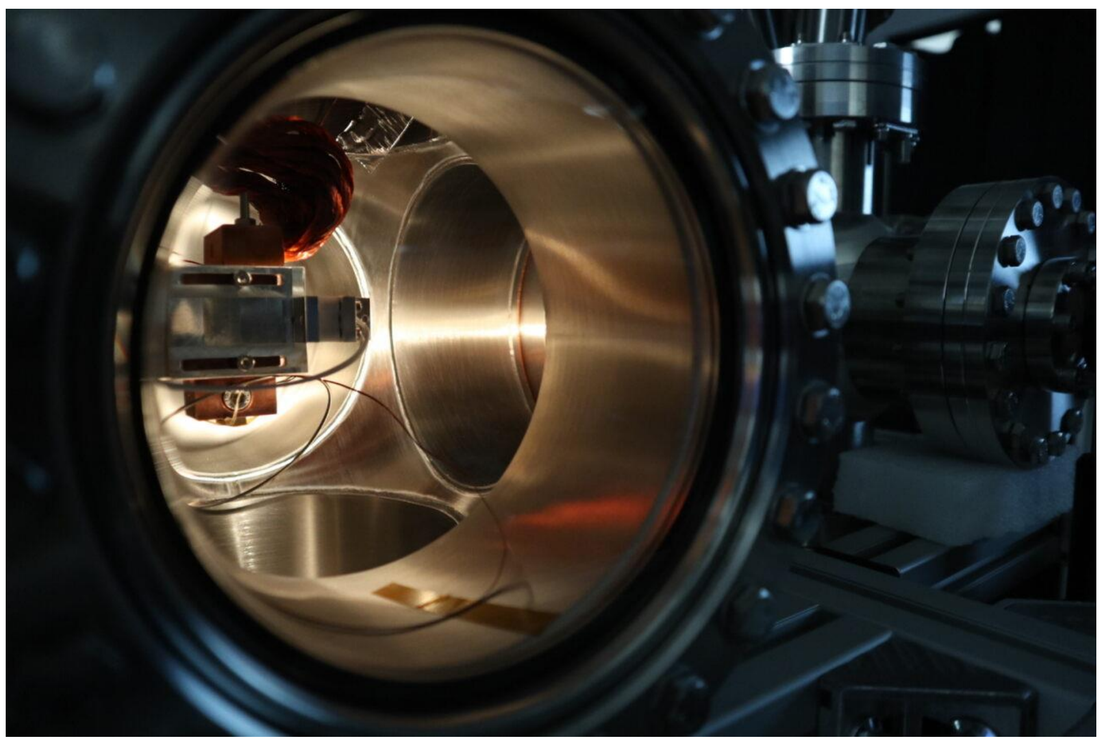
A precise measurement of neutrino mass requires a precise measurement of the electric and magnetic fields. Ramsey spectroscopy of atoms prepared in circular Rydberg states has been demonstrated for mapping magnetic and electric fields.
J. Zou and S. D. Hogan, Phys. Rev. A 107 (2023)



Cyclotron radiation for an 18.6 keV electron in a 0.65 T field is ~18 GHz. This requires antennas capable of collecting this radiation. In particular, the system is inward-facing and low signal strength means an optimised antenna system is important. Optimisations of a system of patch antennas are being investigated for this purpose.
Another option is a waveguide, which can offer high signal-to-noise ratio but limits the range of possible electron motions that can be seen.

Atomic tritium can be produced via molecular dissociation of T_2, using DC discharge.
When combined with a skimmer, a cryogenic, pulsed, supersonic beam of atoms can be formed.

For beta decay to occur, it is necessary to keep atoms in the detection region. A storage ring can provide good time-averaged density of atoms in the detection region by guiding atoms using magnetic fields.



The signal received from a single electron is very small – less than 1 fW. This will need to be amplified up to workable levels without adding large amounts of extra noise. Low-noise quantum amplifiers are being investigated for this purpose.
Two separate types of amplifiers are being investigated, kinetic inductance parametric amplifiers (C.N.Thomas, S.Withington and S.Zhao, arXiv:2206.10512 (2022)) and Superconducting Low-Inductance Undulatory Galvanometer (SLUG) amplifiers.