Determination of the Absolute Neutrino Mass with Quantum Technologies

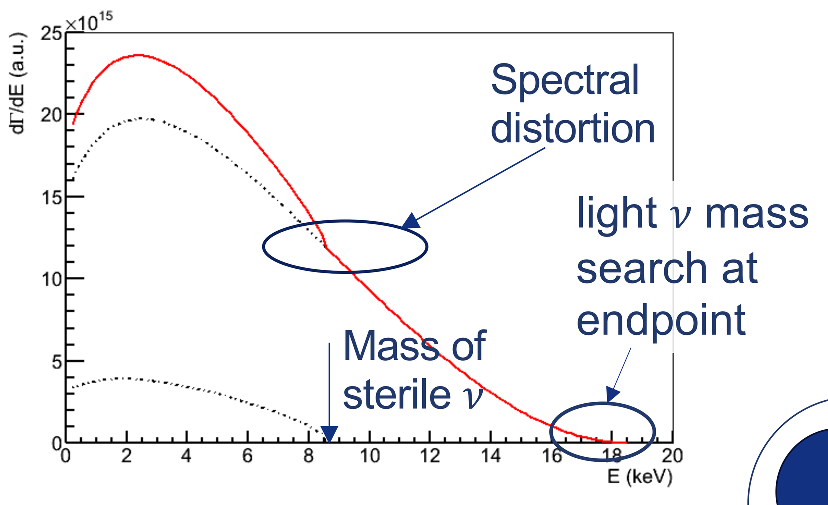
QTNM Quantum Technologies for Neutrino Mass

Nicola McConkey for the QTNM collaboration

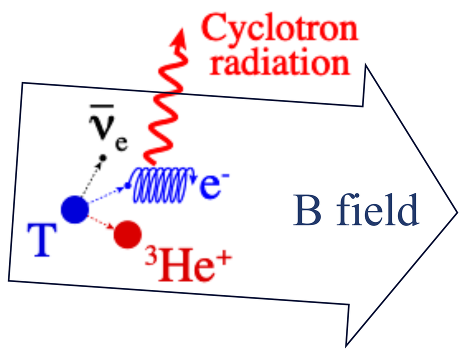
Quantum Technologies for Neutrino Mass (QTNM) Goal: Measure energy of electron emitted in β-decay of *atomic tritium* using *Cyclotron Radiation Emission Spectroscopy (CRES)*

- Absolute neutrino mass measurement with sensitivity O(10meV)
- Model independent kinematic search for sterile neutrinos

CRES Demonstrator Apparatus (CRESDA) brings together techniques from from quantum technology, atomic and molecular physics to measure the differential β-spectrum of T.



CRES: Measurement of the *frequency of electromagnetic radiation* generated due to an electron's *cyclotron motion* in a magnetic field



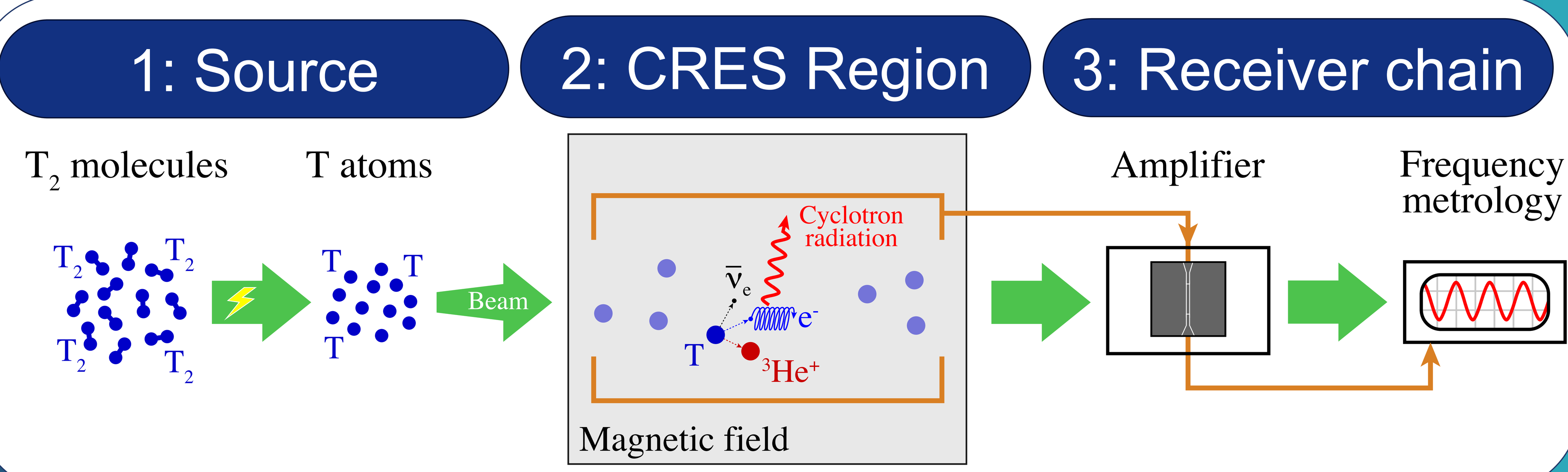
$$f = \frac{1}{2\pi}\frac{eB}{m_e + E_{kin}/c^2}$$

0.65 T

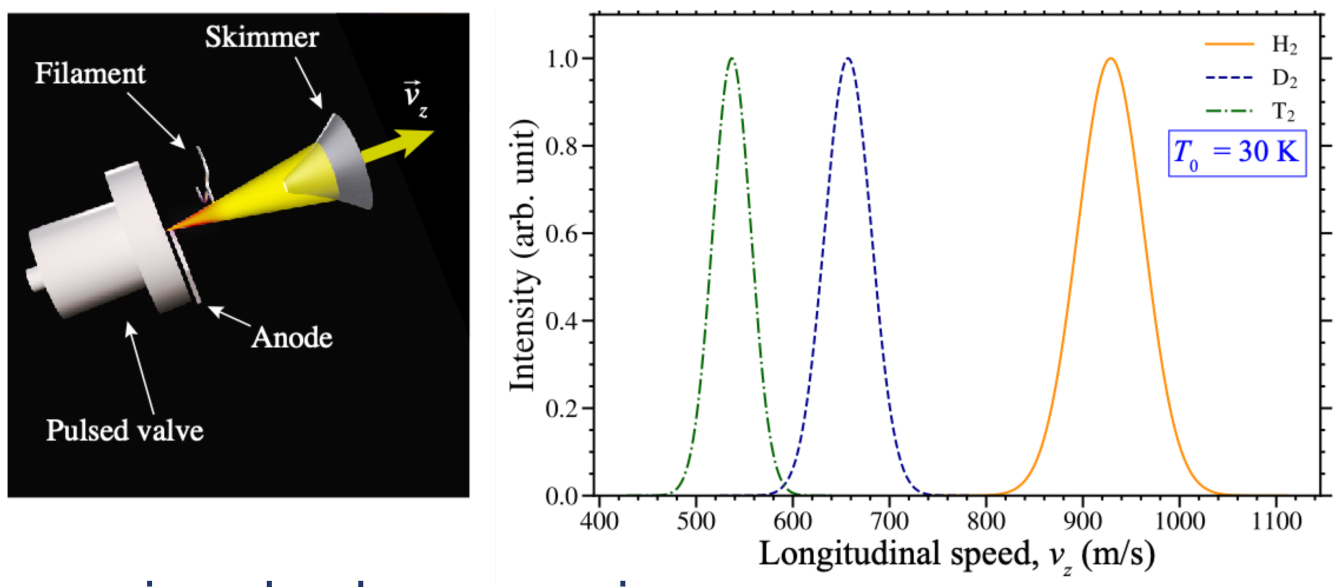
18 GHz

18.6 keV = Q_β

Project 8: arXiv:2303.12055



Require a high intensity atomic tritium source: Create an **Atomic T source** from T_2 using molecular dissociation: a DC discharge seeded with e$^-$ from tungsten filament



Cryogenic pulsed supersonic source

- beam with narrow velocity distribution
- cooled to reduce mean longitudinal velocity
- Characterised using Resonance Enhanced Multi Photon Ionisation (REMPI)

J. Zou and S. D. Hogan, Phys. Rev. A 107 (2023)

CRES signal trapping and collection

Challenge: collecting microwave radiation of sub-fW power

- Must be fast, high efficiency, good signal to noise
- Complex trade off between field of view and gain

Three options under development:

Antennas
Waveguides
Resonant cavities

Electrons can be trapped in a magnetic bottle trap while sufficient power is collected

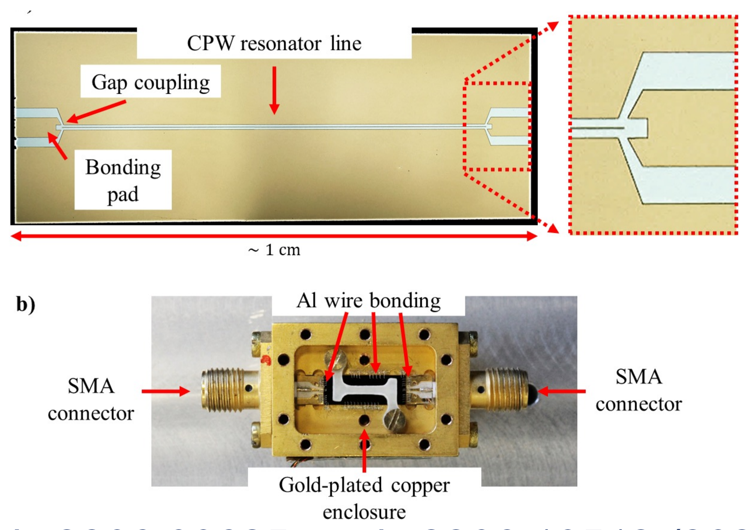
- 1mT local minimum "no-work" trap
- Need to measure for >20us to collect enough power

arXiv:2401.03247v1

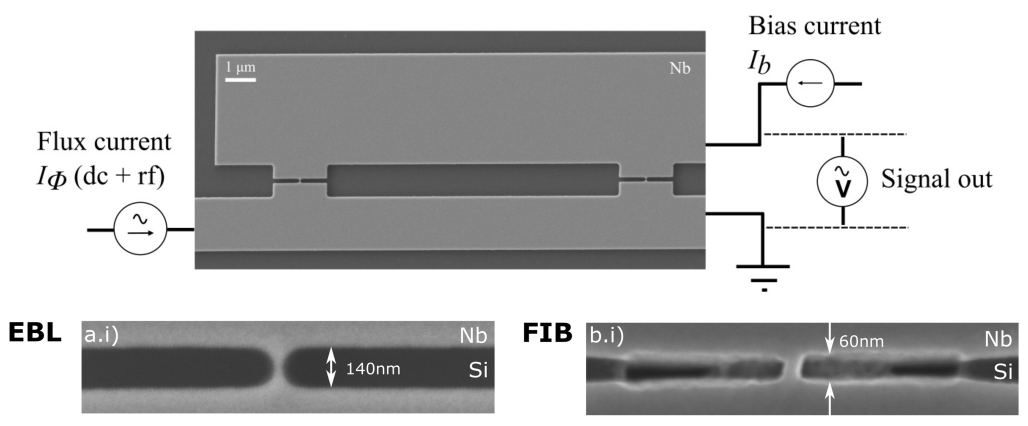
Quantum-limited amplifiers for microwave radiation

Two options under development:

Resonant / Travelling Wave Kinetic Inductance Parametric Amplifiers: two port resonators operating as amplifiers



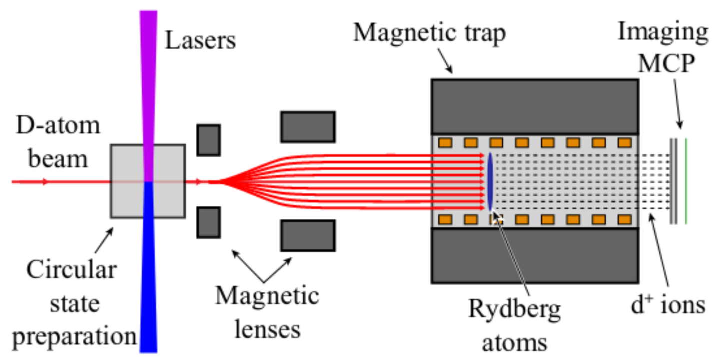
Based on **Superconducting Low Inductance Undulatory Galvanometers (SLUG) and** utilising nanobridge weak link **Josephson junctions**



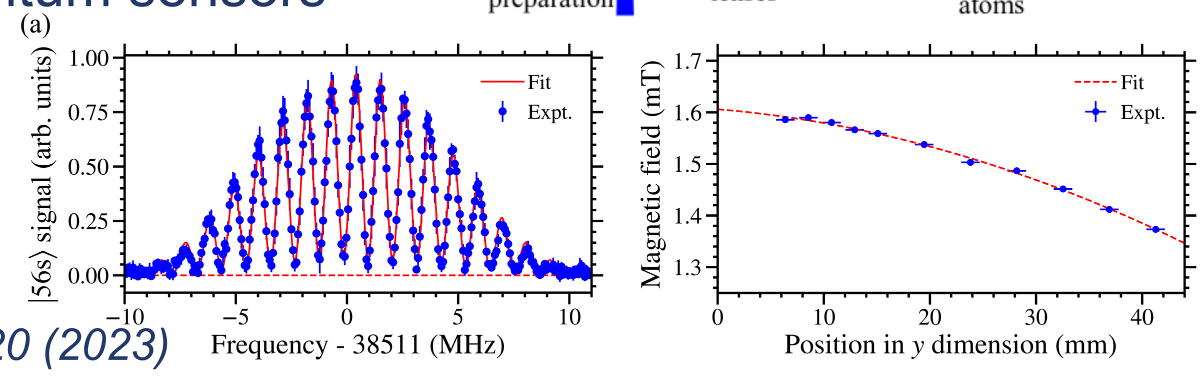
arxiv:2306.00685, arxiv:2206.10512 (2022)

B field directly affects sensitivity to neutrino mass
Require a uniform and well understood B field

Use Rydberg atom magnetometry and electrometry to measure B-field: T atoms in circular Rydberg states as quantum sensors



Measure Ramsey spectrum of transition between circular Rydberg states

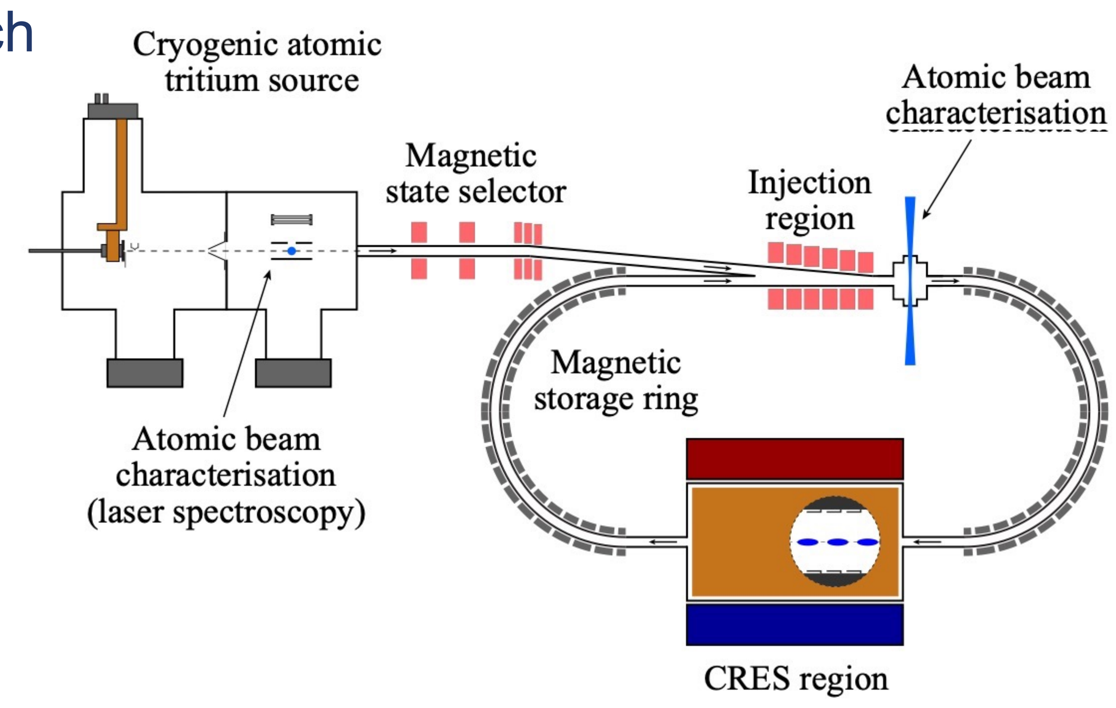


Zou and Hogan, Phys. Rev. A **107**, *062820 (2023)*

Current status and plans

- Successful demonstrations of atomic dissociation, B field measurements, patch antennas, resonant cavities, amplifier performance, and warm down-mixing
- Detector simulations, modelling and trigger have been developed
- **CRESDA will integrate these technologies**
- CRESDA0 is currently under design:
- First phase readout chain will include MW source, resonant cavity, readout by HEMT at 4K
- Next stage will include 0.65T magnetic field, magnetic trap, and electron source with quantum amplifiers cooled to mK included in the system
- First neutrino measurements with atomic tritium follow! O(eV) sensitivity

CRESDA Schematic



QTNM aims to demonstrate technology suitable for making the ultimate neutrino mass measurement!

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