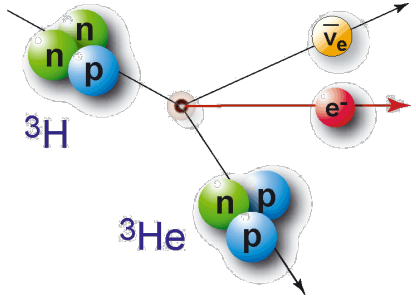
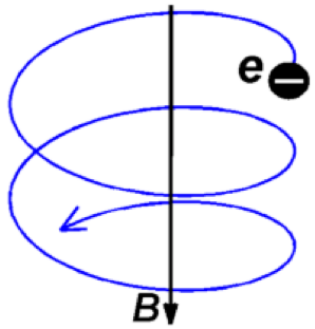
Quantum Technologies for Neutrino Mass

UCL · University of Cambridge · NPL National Physical Laboratory · Warwick The University of Warwick · Prifysgol Abertawe Swansea University

A collaboration of particle, atomic and solid state physicists, electronics engineers and quantum sensor experts





Cyclotron Radiation Emission Spectroscopy (CRES)

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

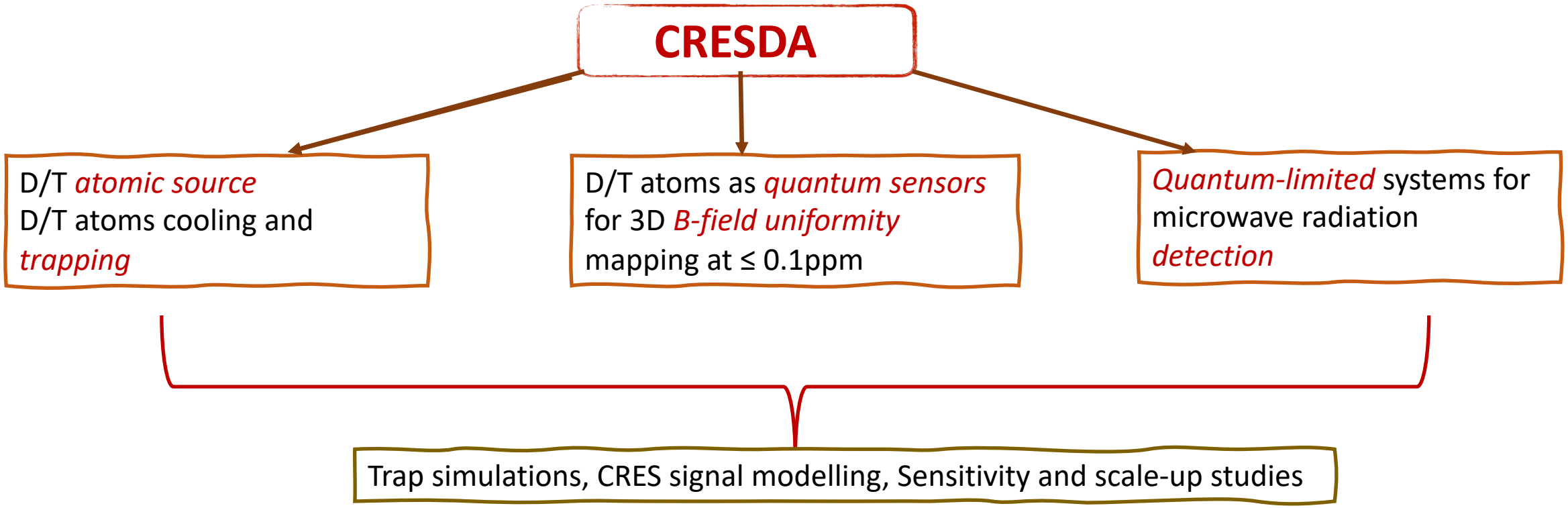
Feasibility of e-spectroscopy with CRES demonstrated by Project 8

Goal: To build on recent **investment** in **quantum sensors** to assess feasibility of an **experiment** capable of a positive **neutrino mass measurement** from **^{3}H β-decay** using **CRES** technology.

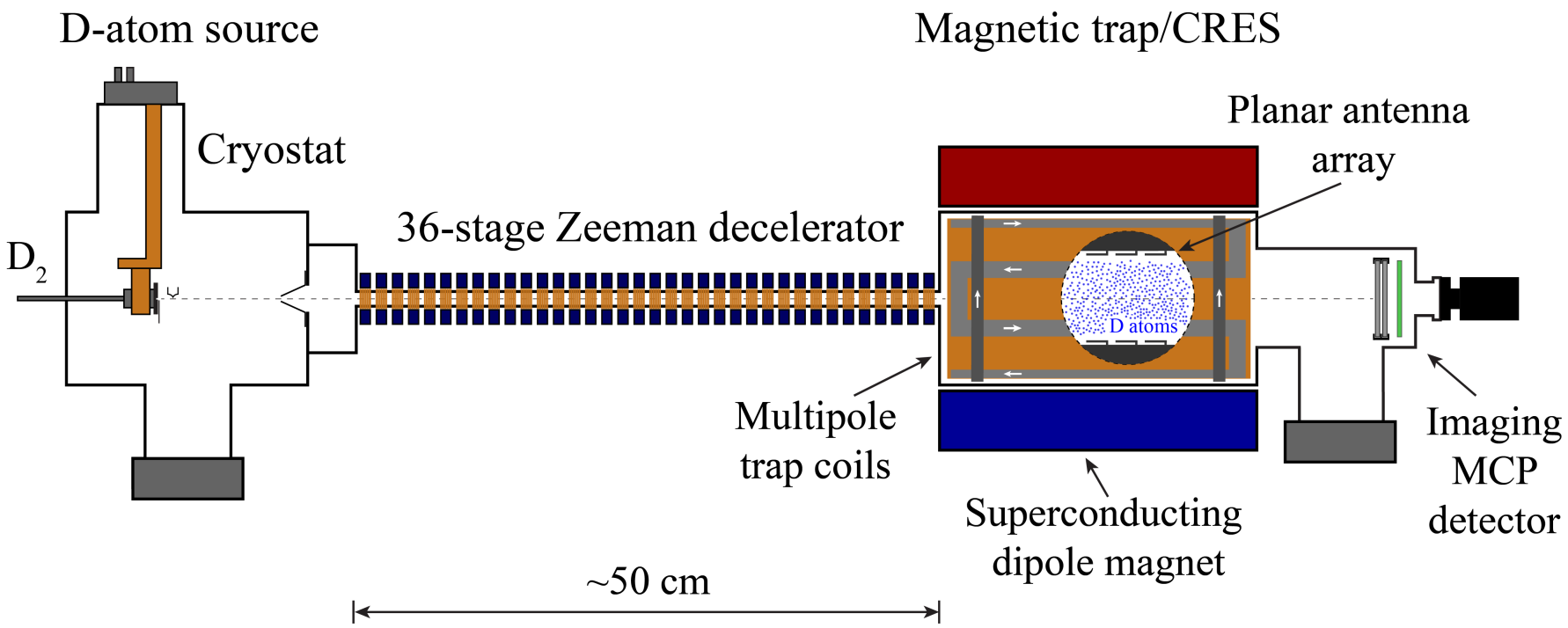
QTNM is one of 7 projects funded for 3 years under the UKRI **QTFP*** Programme

* **Q**uantum **T**echnologies for **F**undamental **P**hysics

The aim is to build **CRES D**emonstration **A**pparatus, **CRESDA**, based on Deuterium-atoms but "Tritium-ready"



CRESDA. Atomic Source and Magnetic Trap.

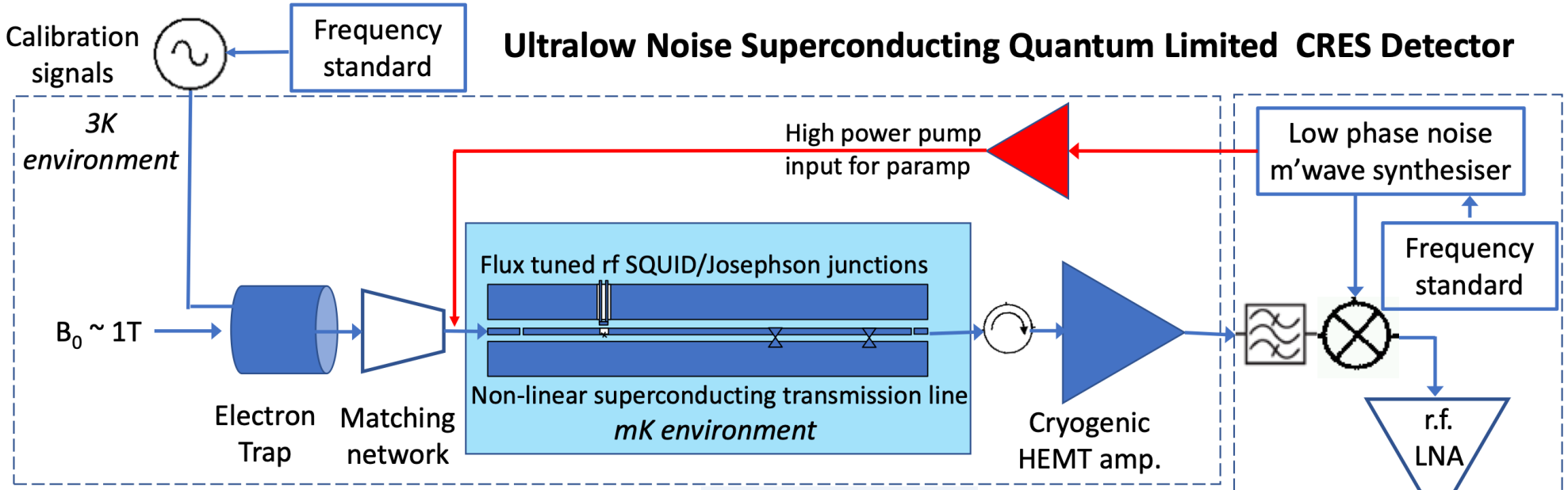


- A number of designs under consideration
- 1L trap with ρ~10^{12}-10^{14} cm^{-3}.
- Initially operate with D-atoms, tritium ready.

- Extensive characterisation of trap's content (density, velocity distributions…)
- B-field mapping with ≤ 0.1ppm using D-atoms as quantum sensors
- D_2 background characterisation

CRESDA. Quantum MW-Spectrometer.

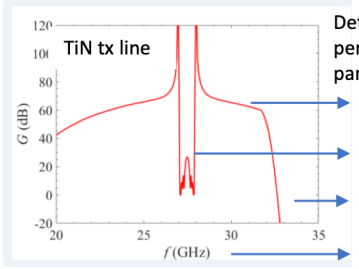
MW signal → Antennas → SQUID or JTWPA preamp → HEMT amp



Challenge of millimetre-wave (25-30 GHz) ultra-low-noise amplifiers:

- Push superconducting microwave SQUID amplifiers up in frequency
- Push superconducting parametric amplifiers down in frequency
- High gain quantum-limited noise performance possible

Draws heavily on major investments by funding agencies in establishing superconducting device processing and measurement labs



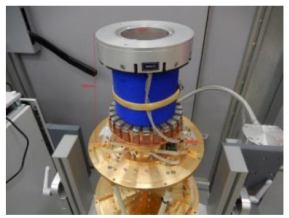
Detailed simulations verify performance of superconducting parametric amplifier: arXiv:1904.07673

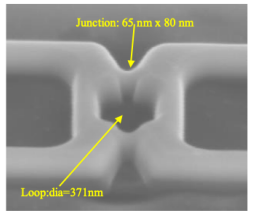
High gain

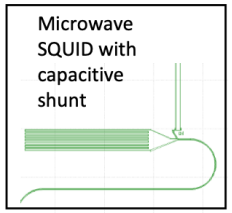
$f_{\mathrm{pump}} = 27.5$ GHz

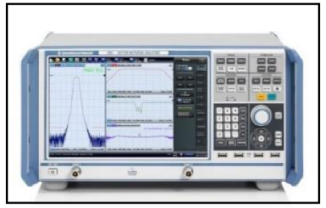
DoS gap cut-off

Signal frequency

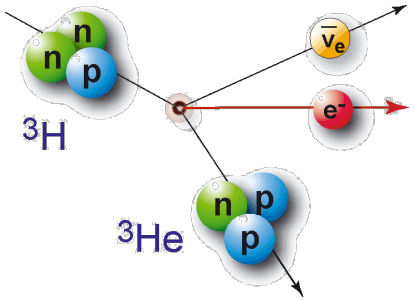








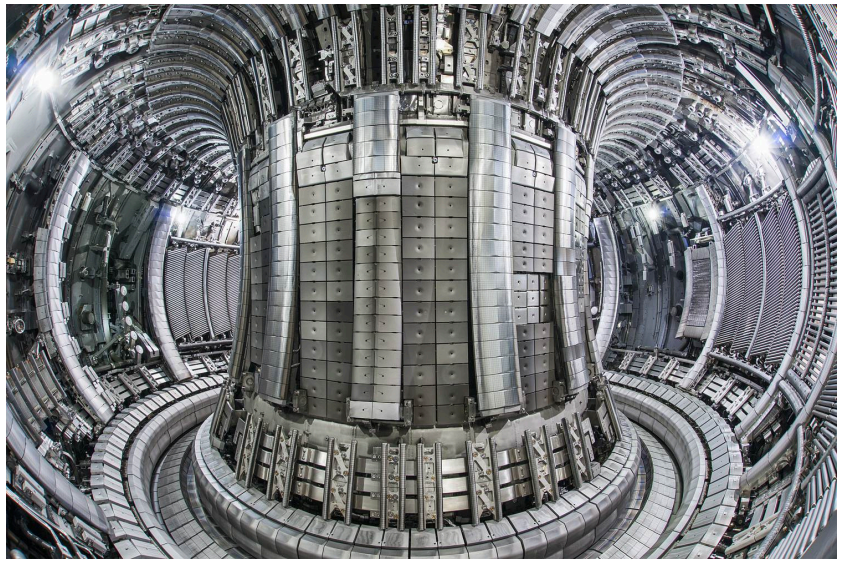
QTNM Future Outlook



A (VERY) tentative timeline

- Current project: 2021-2024
  - Technology demonstration with Deuterium which is Tritium ready

- Next step. 2025-2029
  - Moving CRESDA to a Tritium facility (strong engagement with Culham)
  - Tritium phase demonstration
  - *O*(eV) sensitivity



- ”Ultimate” international project > 2029
  - Consolidate technological breakthroughs (QTNM, Project-8, …) to build and operate a detector with a phased sensitivity: 100 meV ⇨ 50 meV ⇨ 10 meV plus sterile neutrino programme

CCFE
CULHAM CENTRE FOR FUSION ENERGY