Quantum Technologies for Neutrino Mass

17 members (and growing)

UCL

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Determination of Neutrino Mass with Quantum Technologies

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

PPTAP Workshop
Cyberspace
3 June 2021

Ruben Saakyan (UCL)

Neutrino oscillations → ***$m_\nu \neq 0$*** → ***Window to New Physics***

Absolute mass not known → complementarity of cosmological observations and **laboratory measurements**

Model independent measurement: electron spectrum near end-point of $\boldsymbol{\beta}$*-decay*

E. Fermi, Z. Phys. 88 (1934) 161

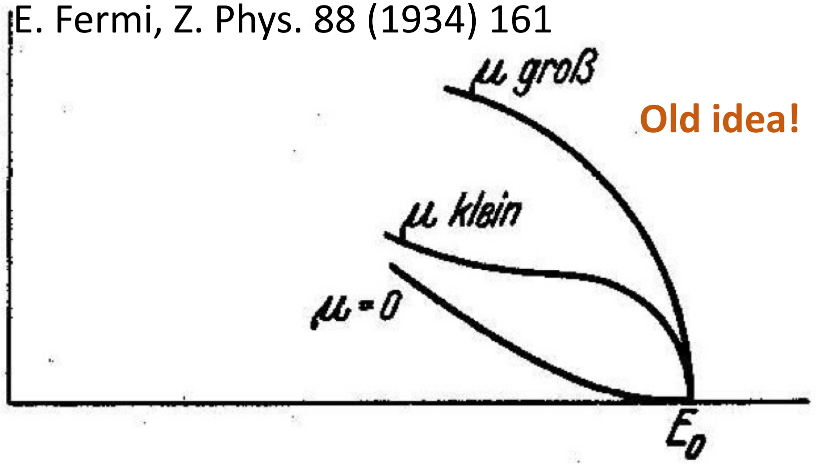
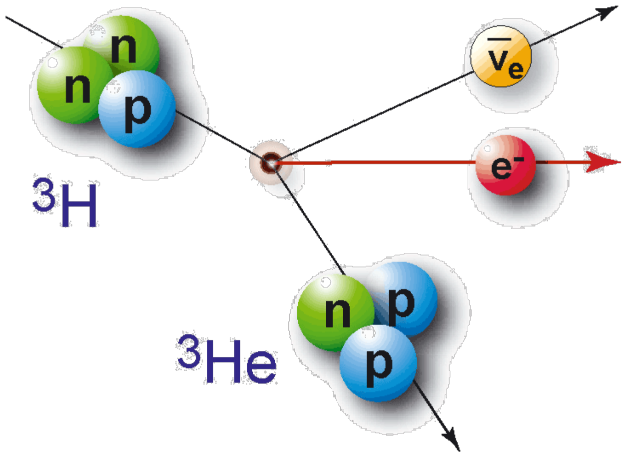
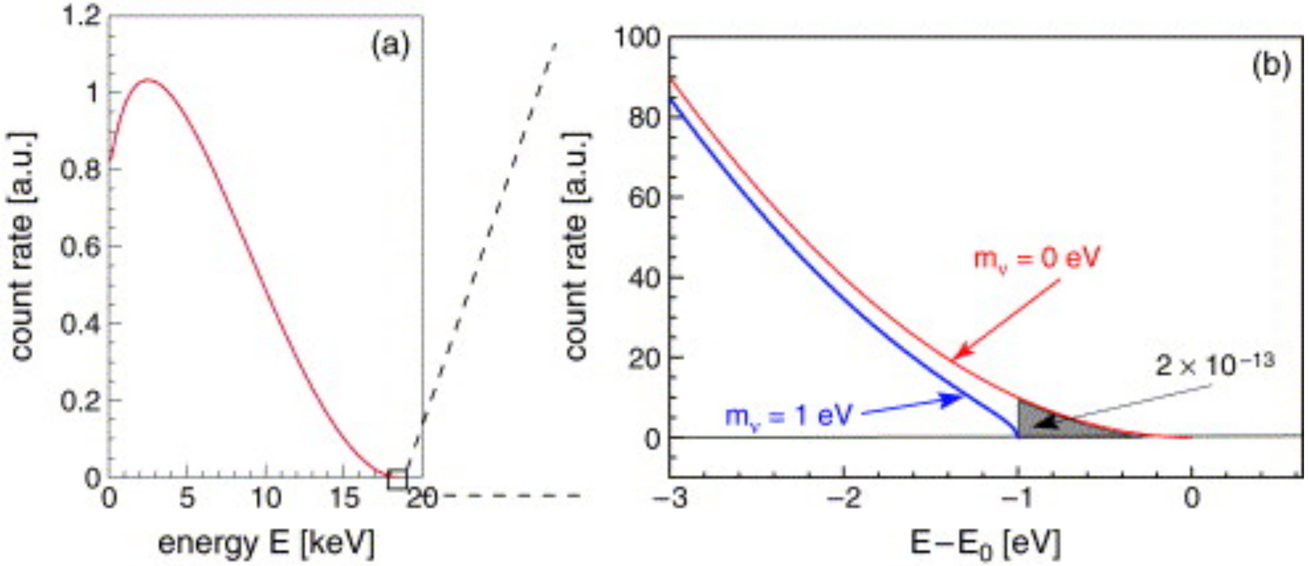


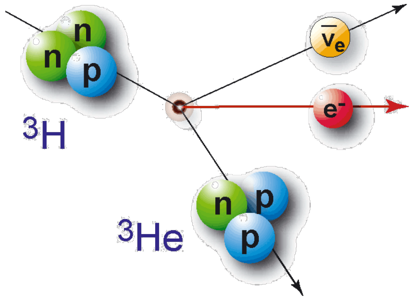
Fig. 1.

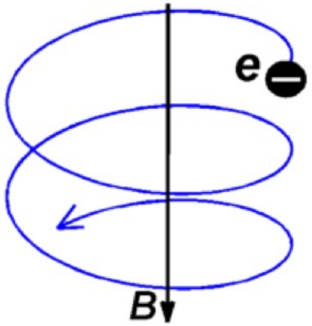
Old idea!



- **Current upper limit, < 0.8 eV (KATRIN)**
- **Lower bound (from ν-oscillations) > 0.009 eV (!)** → ***Requires a "quantum leap" in technology***







Cyclotron Radiation Emission Spectroscopy (CRES)

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

Challenges:

- ***Atomic tritium***
- ***Sub fW power***
- ***< 1ppm resolution***

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 funded for 3 years under the UKRI **QTFP** Programme

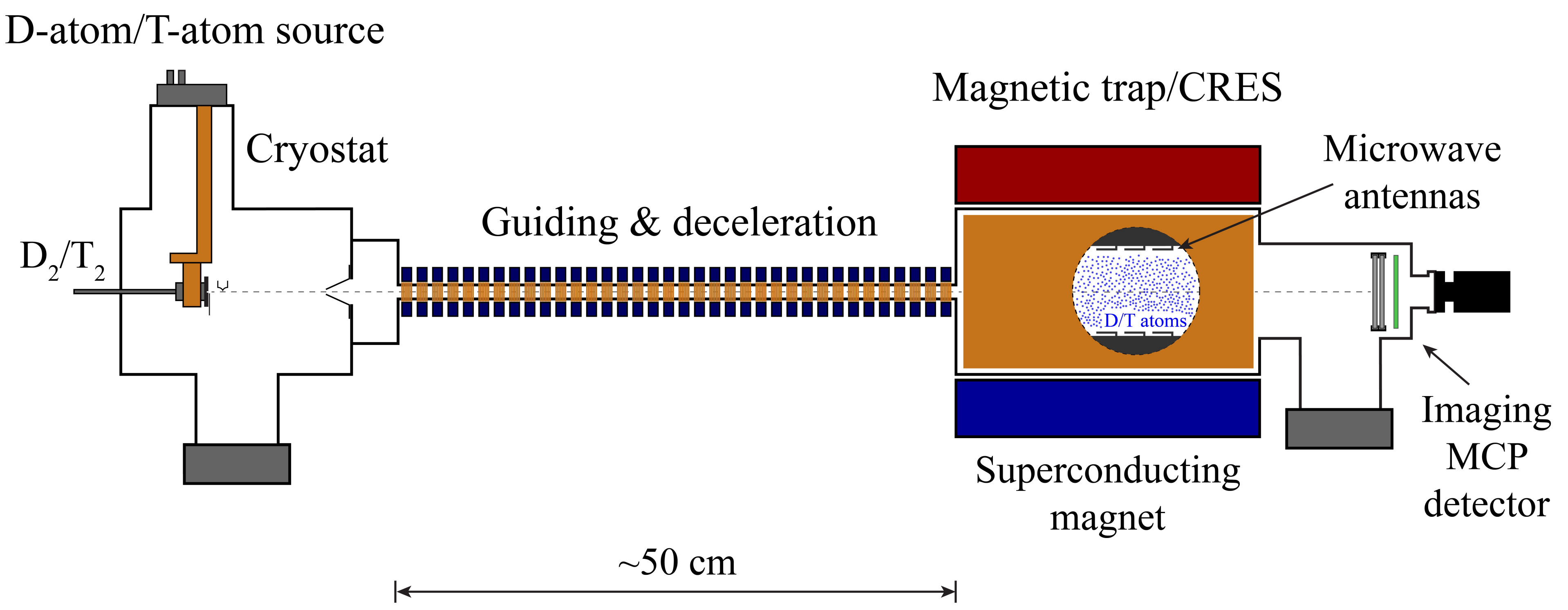
The aim is to build **CRES D**emonstration **A**pparatus, **CRESDA**, based on Deuterium-atoms but “Tritium-ready”

CRESDA

- D/T *atomic source*
  D/T atoms cooling and *confinement*
- D/T atoms as *quantum sensors* for 3D *B-field uniformity* mapping at ≤ 0.1ppm
- *Quantum-limited* systems for microwave radiation *detection*

Trap simulations, CRES signal modelling, Sensitivity and scale-up studies

CRESDA. Atomic Source and Atom Confinement.

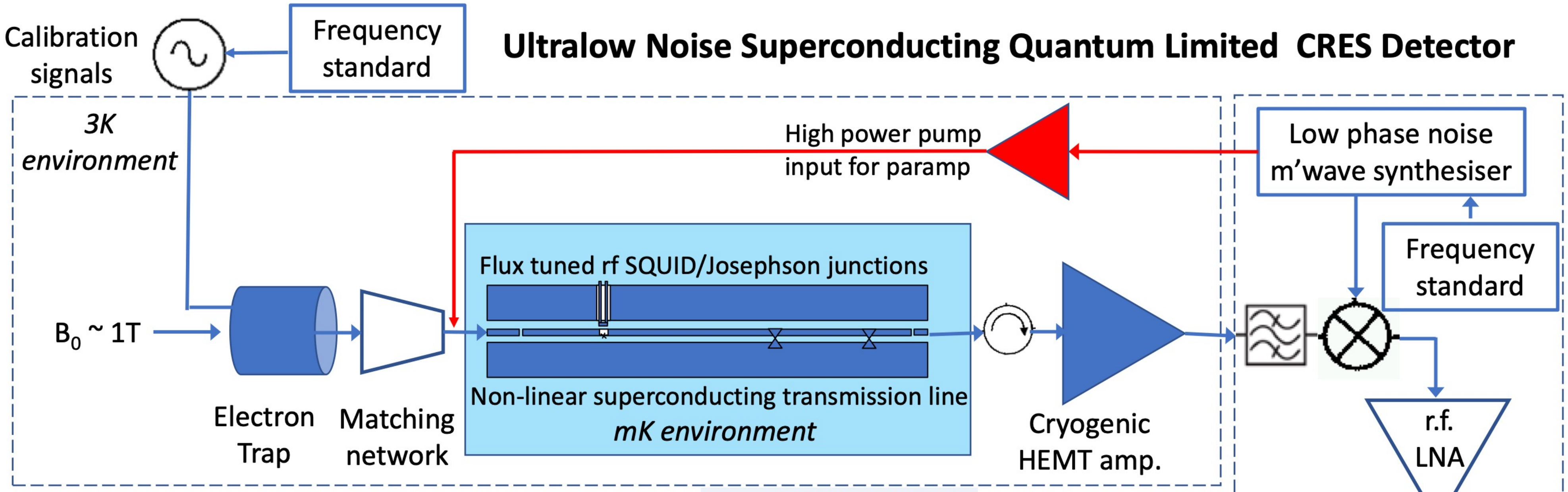


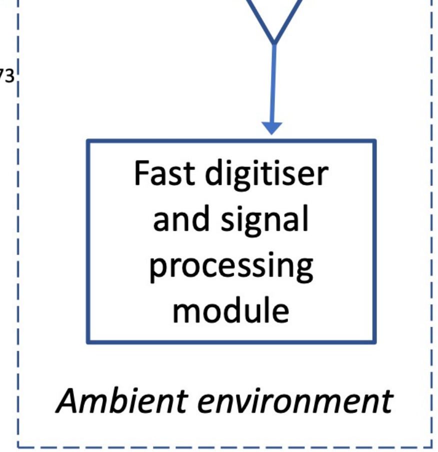
- A number of designs under consideration
- 1L CRES region with $\boldsymbol{\rho}$~10^{12}-10^{14} cm^{-3}.
- Initially operate with D-atoms, tritium ready.

- Extensive characterisation of confined atoms (density, velocity distributions…)
- B-field mapping with ≤ 0.1ppm using D/T-atoms as quantum sensors
- D_2/T_2 background characterisation

CRESDA. Quantum MW-Spectrometer.

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

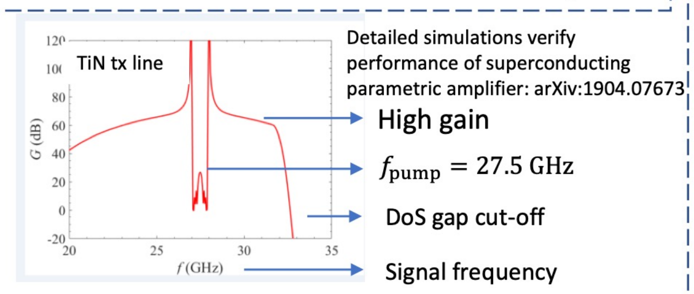


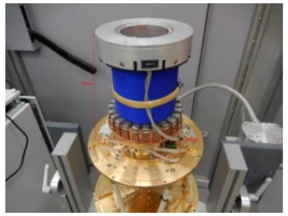


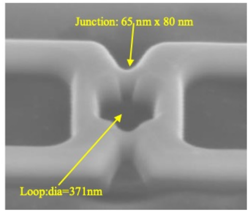
Challenge of millimetre-wave (25-30 GHz) ultra-low-noise amplifiers:

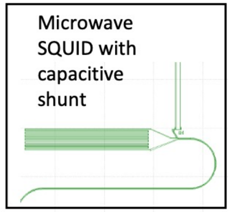
- Push superconducting microwave SQUID amplifiers up in frequency
- Push superconducting parametric amplifiers down in frequency
- High gain quantum-limited noise performance possible

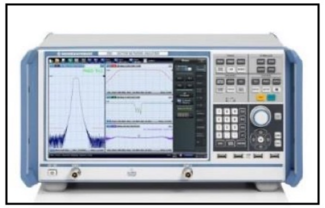
Draws heavily on major investments by funding agencies in establishing superconducting device processing and measurement labs



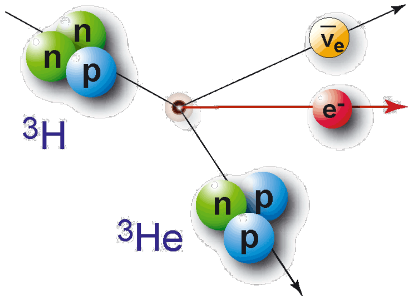






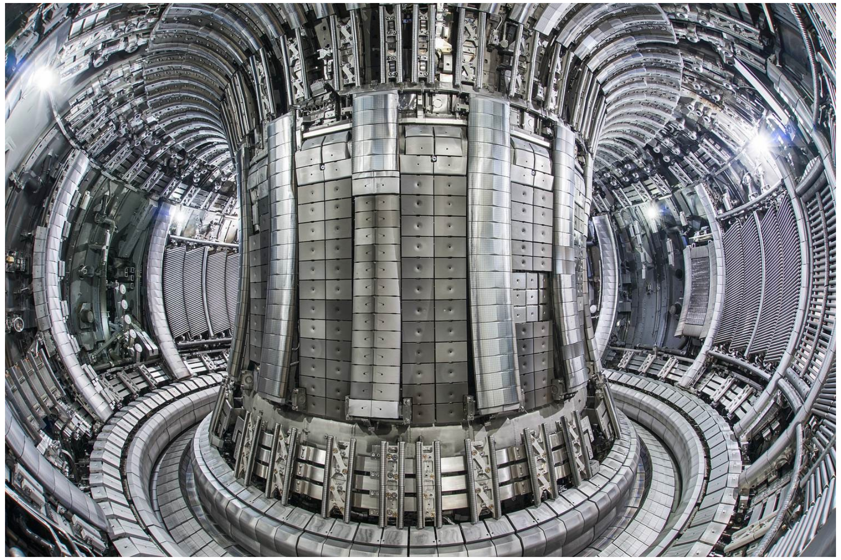


QTNM Future Outlook



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

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