A Resonant Cavity-Based CRES Demonstrator on the Path to a More Precise Neutrino Mass Measurement with Project 8

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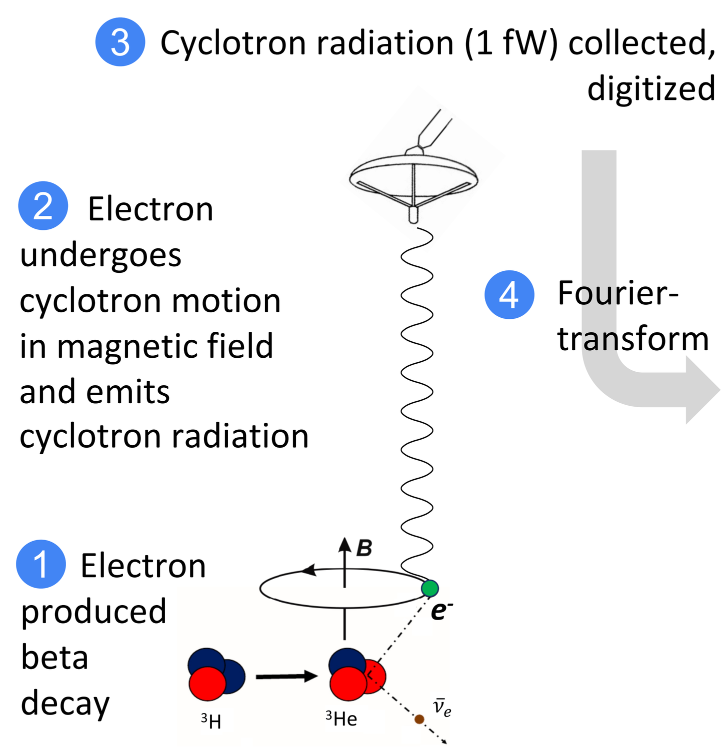
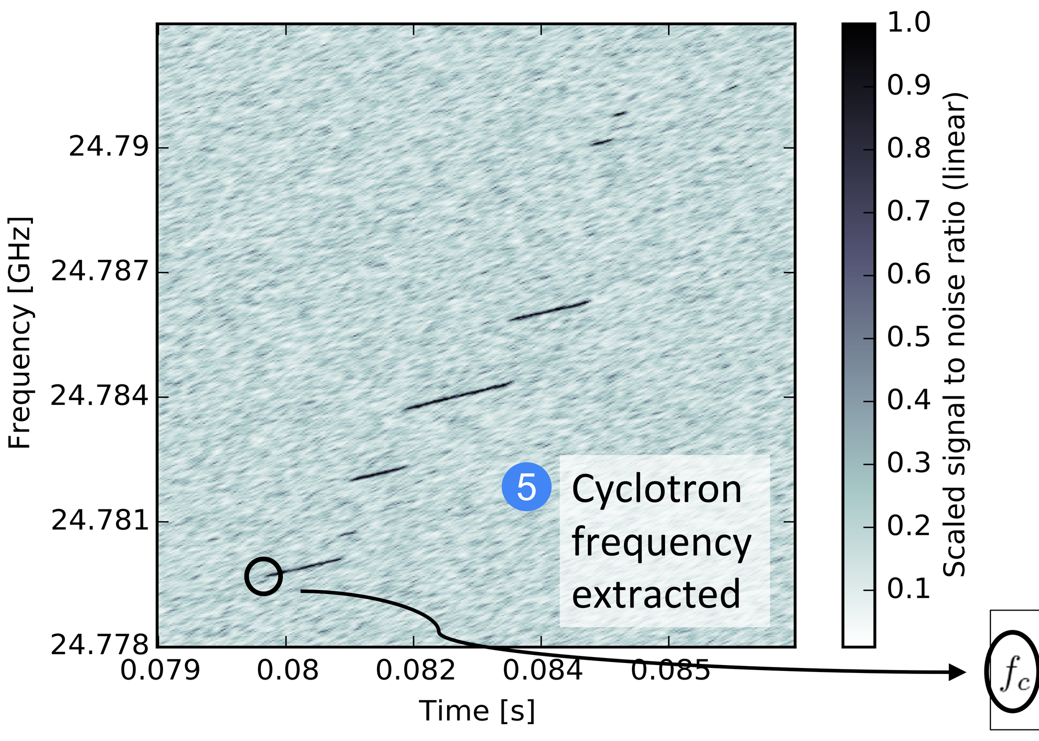
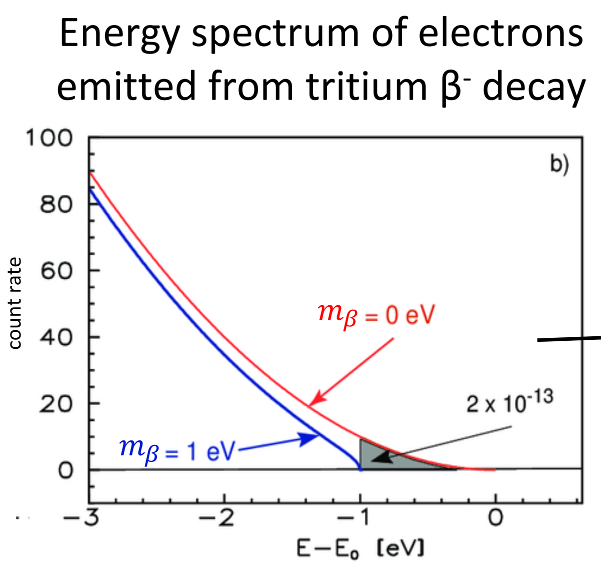
Project 8: measuring neutrino mass by observing tritium β- decay with Cyclotron Radiation Emission Spectroscopy (CRES)





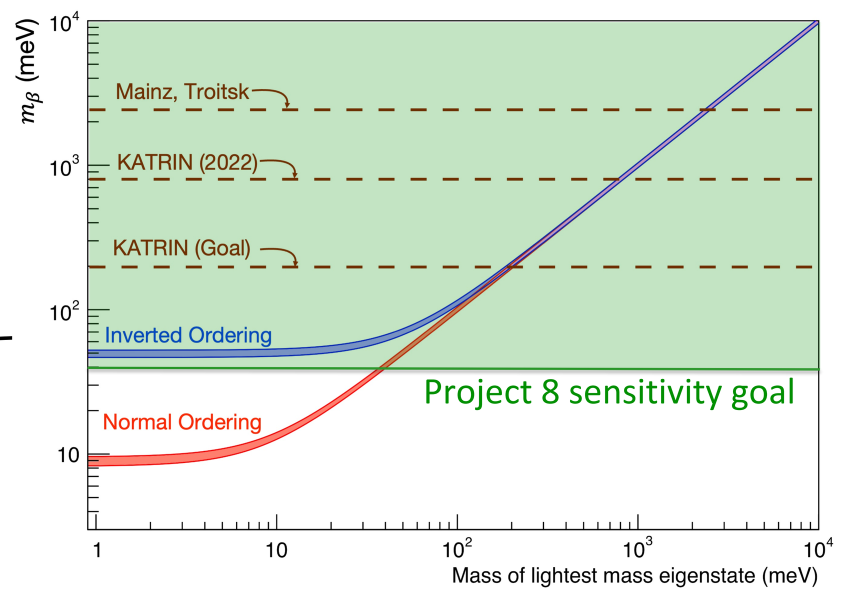


$$f_c = \frac{f_{c,0}}{\gamma} = \frac{1}{2\pi}\frac{eB}{m_e + E_{kin}/c^2}$$

6 Electron kinetic energy assessed

7 Repeated for many decays

8 Neutrino mass info extracted from spectrum



Goal: sensitivity to 40 meV, measuring the mass or excluding the inverted ordering. Simultaneous sensitivity to active and sterile neutrinos.

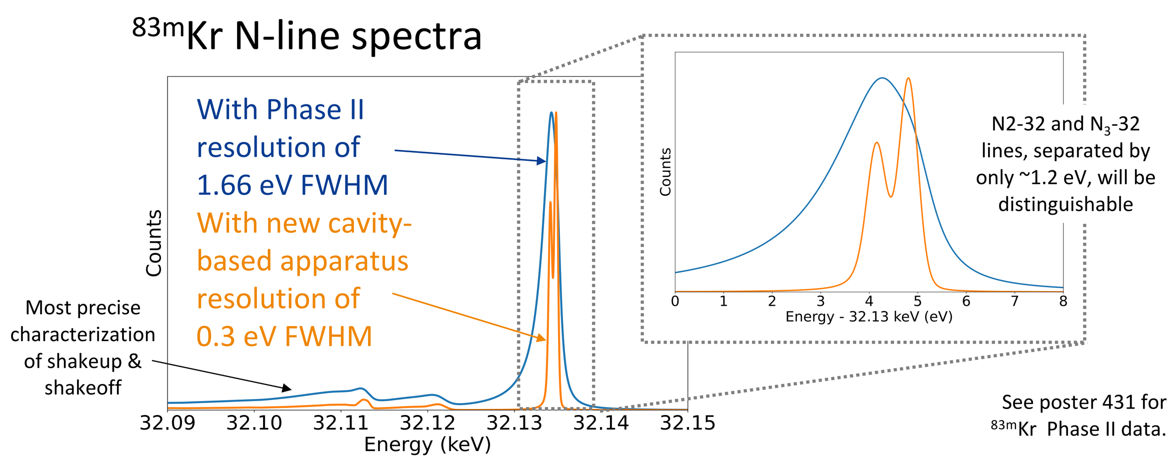
New CRES capabilities needed to improve neutrino mass sensitivity

- Project 8 Phase II set limit of ~152 eV on m_β with zero background and demonstrated instrumental resolution of 1.66 eV. (See poster 431.)
- To achieve sensitivity to 40 meV, need orders of magnitude **higher statistics** and factor of ~5 **narrower detector response**. This **detector response width must be characterized** to 1%. (See poster 577.)
- A cold atomic tritium source is also needed. (See posters 532, 573.)

New cavity-based apparatus will demonstrate many technologies needed to reach 40 meV

- Cavity-based geometry is compatible with orders-of-magnitude **increased detector volume**.
- Improved signal-to-noise ratio from cavity-enhanced cyclotron emission will enable **higher detection efficiency**.
- A <0.3-eV-wide electron gun calibration source will enable **improved detector response characterization** and **absolute magnetic field calibration**. (See also poster 594.)
- Well-understood signal morphology **embeds magnetic field calibration information in the CRES data**.

Science with this detector



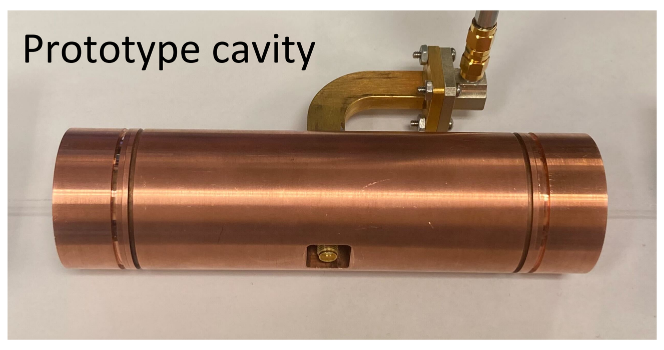
- K-, L-, M-, N- conversion electrons from ^{83m}Kr will be probed with highest resolution yet
- With absolute magnetic field measurements from electron gun and other magnetometry, this will enable an important systematic check for KATRIN

Cavity development and prototyping

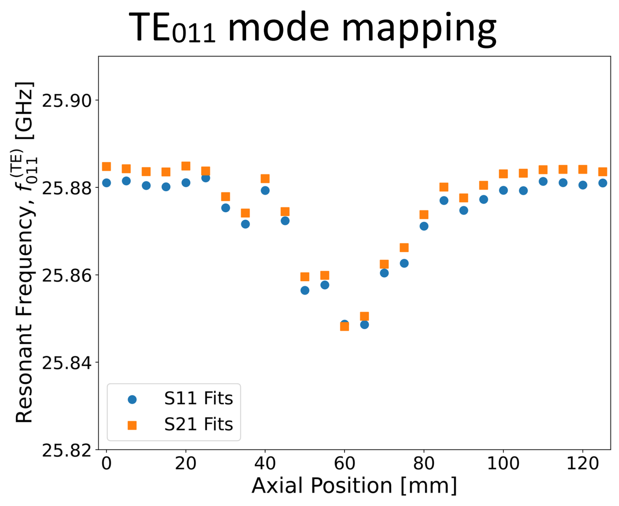
- Designed cavity with TE_{011} mode at 26 GHz to operate in 1 T magnetic field
- CRES signal coupling to TE_{011} mode is read out via aperture-coupled WR42 waveguide
- Over-coupling for larger bandwidth to increase detection efficiency
- Prototype manufactured at MIT, mode mapped by pulling small bead through the cavity, which changes frequency as:

$$\frac{\Delta\omega}{\omega} = \frac{-(\epsilon-1)}{2}\frac{V_{bead}}{V_{cavity}}\frac{E(\vec{x})^2}{\langle E(\vec{x})^2\rangle}$$

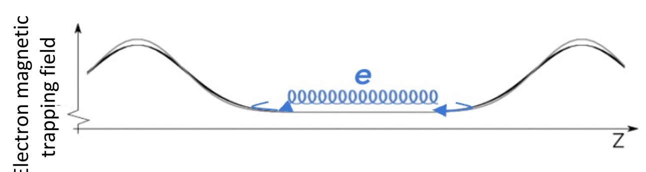
Prototype cavity



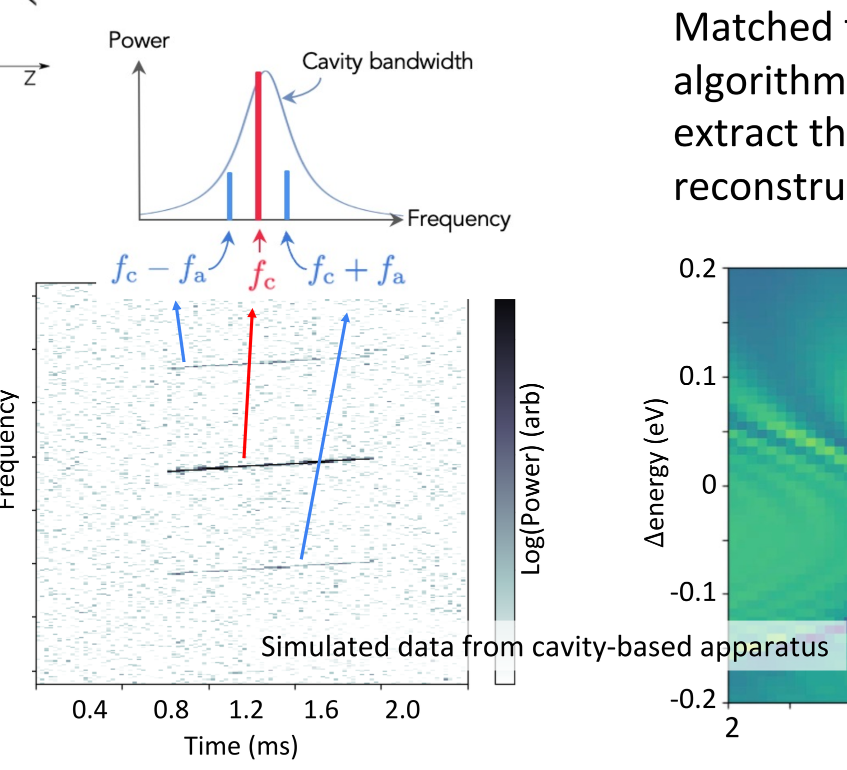
TE_{011} mode mapping



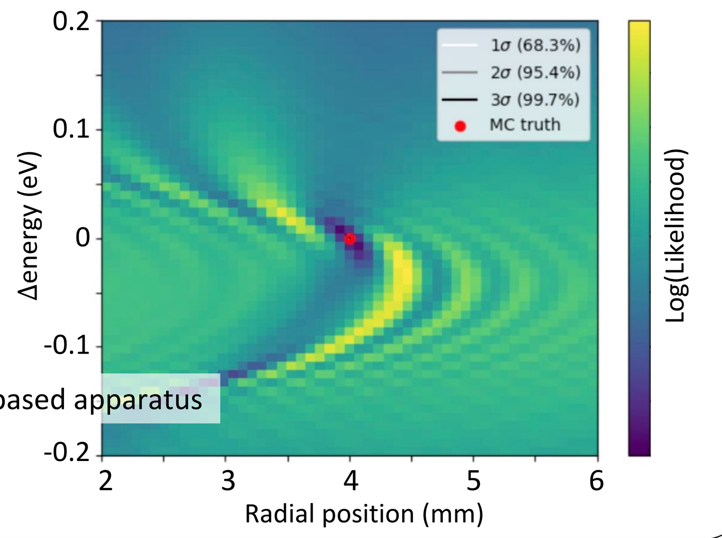
Precise electron-by-electron energy reconstruction



- Electrons that explore different regions of the magnetic trap experience slightly different average magnetic fields
- Electron trajectory information is encoded in spacing and power in RF sidebands of CRES signal

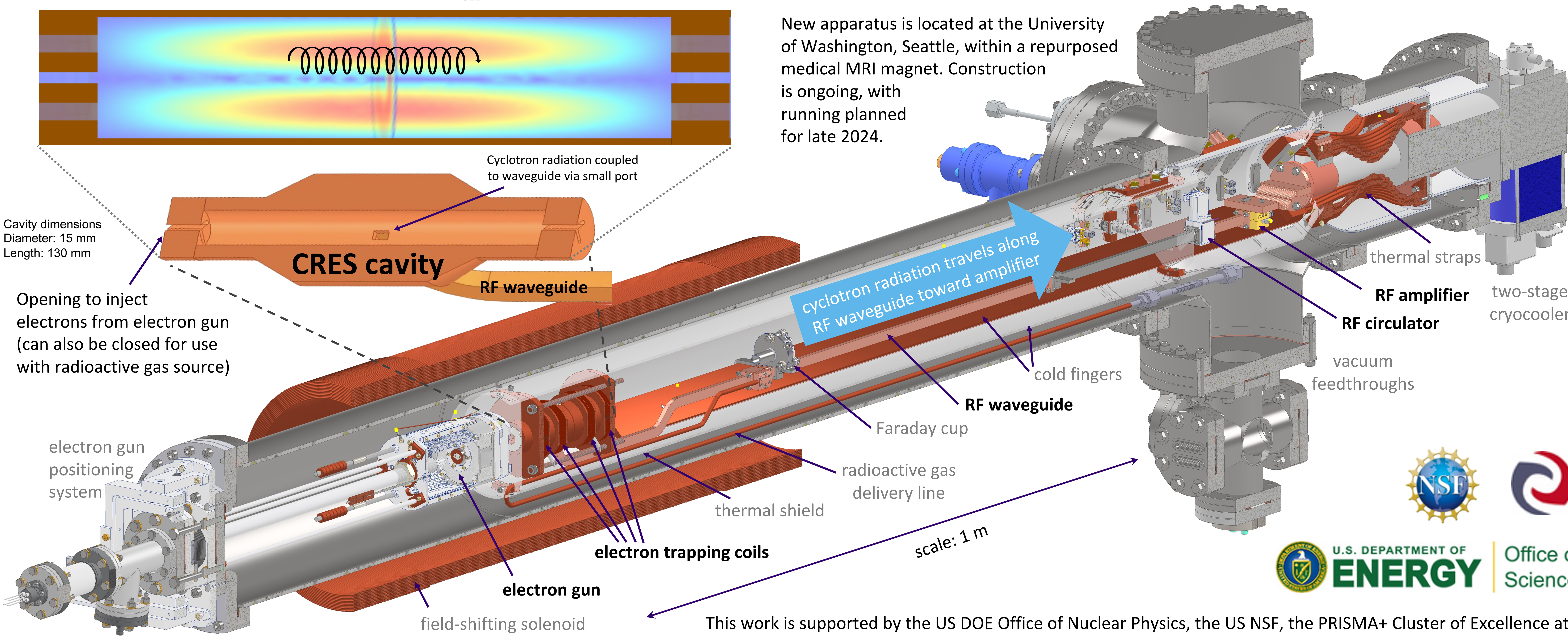


Matched filtering and deep learning algorithms under development can extract this information to reconstruct electron energy



Electron's cyclotron radiation couples to TE_{011} resonant mode of cavity

New apparatus is located at the University of Washington, Seattle, within a repurposed medical MRI magnet. Construction is ongoing, with running planned for late 2024.



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