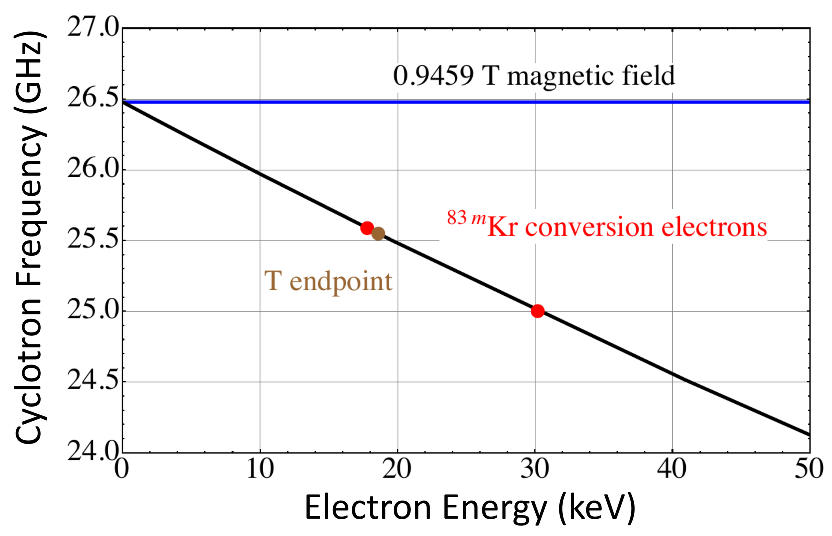
Measuring the Tritium β-Decay Spectrum using Cyclotron Radiation Emission Spectroscopy

The Project 8 Collaboration

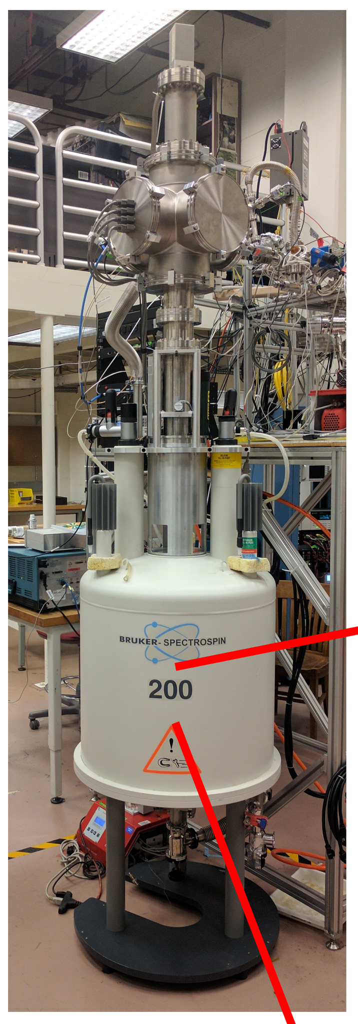
I. The CRES Technique

- We can precisely measure the kinetic energies of electrons in a known magnetic field by detecting their cyclotron radiation
- The cyclotron frequency for a charged particle is inversely proportional to its total energy
- This technique was proposed for use in tritium **β**-decay spectroscopy in 2009 [1]
- CRES was first demonstrated using internal conversion electrons from ^{83m}Kr in 2014 [2]

$$f = \frac{f_c}{\gamma} = \frac{1}{2\pi} \cdot \frac{eB}{K/_{c^2} + m_e}$$



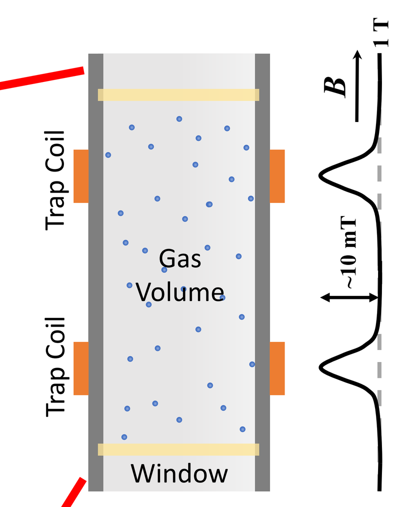
II. The Phase II System



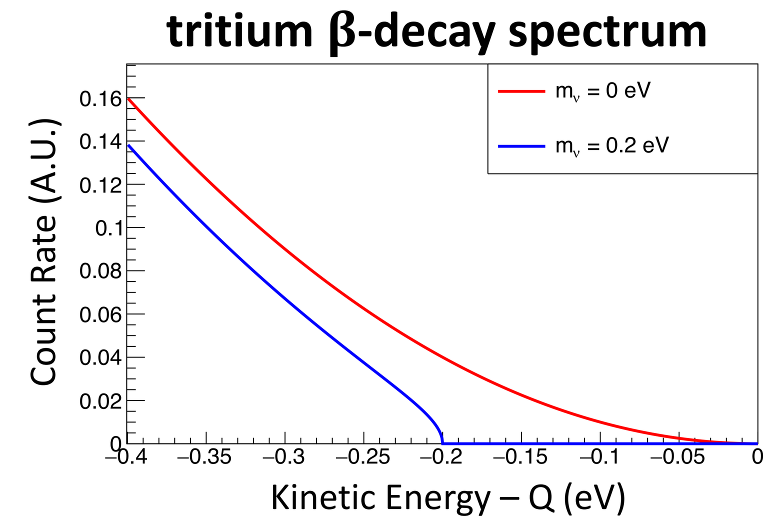
- Superconducting solenoid magnet provides the background B field
- Waveguide insert with trap coils lives in the magnet bore
- Electron spin resonance monitors background B field

Goal of Phase II: a demonstration of the CRES technique applied to tritium beta decay

- Project 8 is pursuing an ultimate sensitivity of $m_\nu < 40$ meV/c^2 (90% C.L.)
- In Phase II we aim to measure the last 2 keV (≈100 MHz) of the spectrum
- Sensitivity to m_ν will be 10-100 eV/c^2
- This poster shows recent Phase II progress



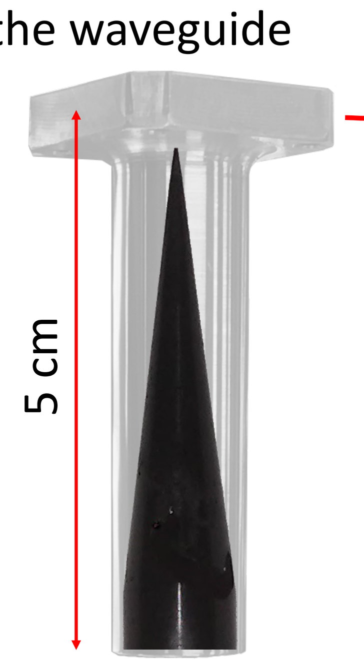
Endpoint of the tritium β-decay spectrum



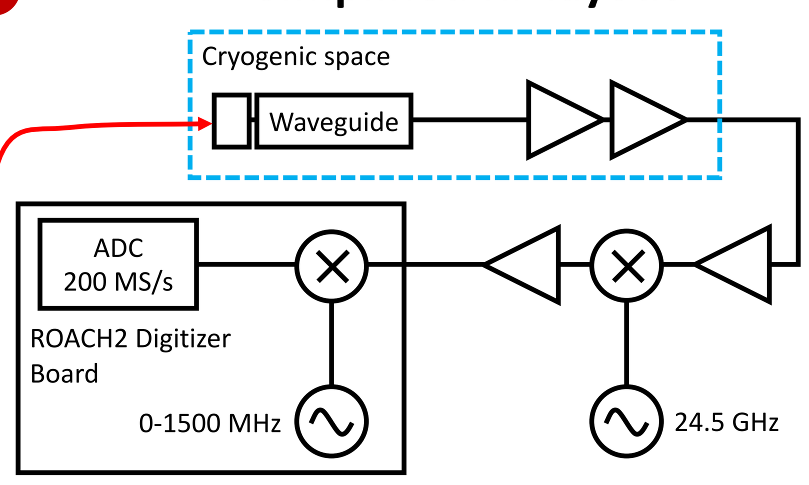
III. RF System

Improvements are focused on reliability, signal-to-noise ratio, and understanding CRES phenomenology

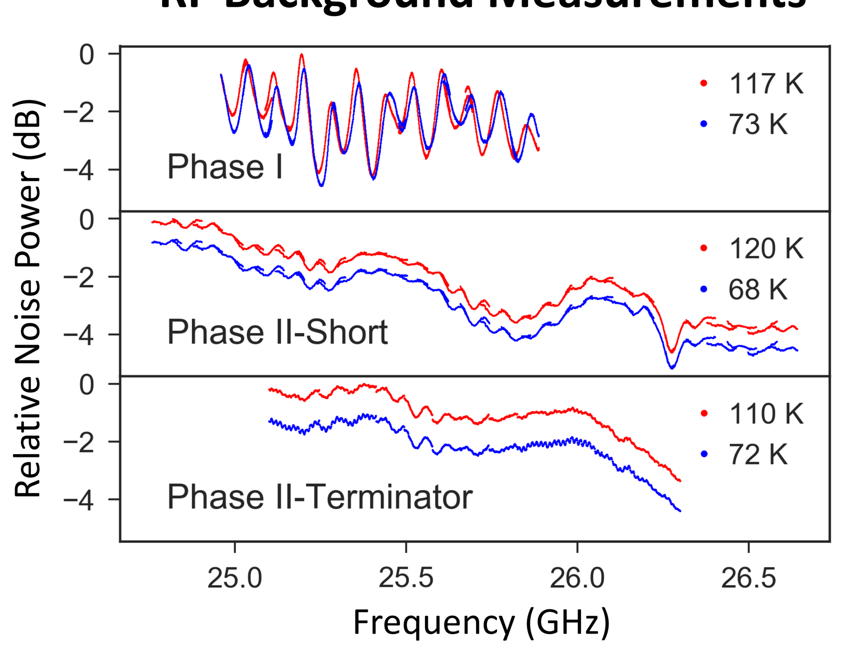
An RF-absorbing terminator is installed at the terminal end of the waveguide



Simplified RF layout



RF Background Measurements



IV. Insert and Field Shifting Solenoid

Waveguide Insert

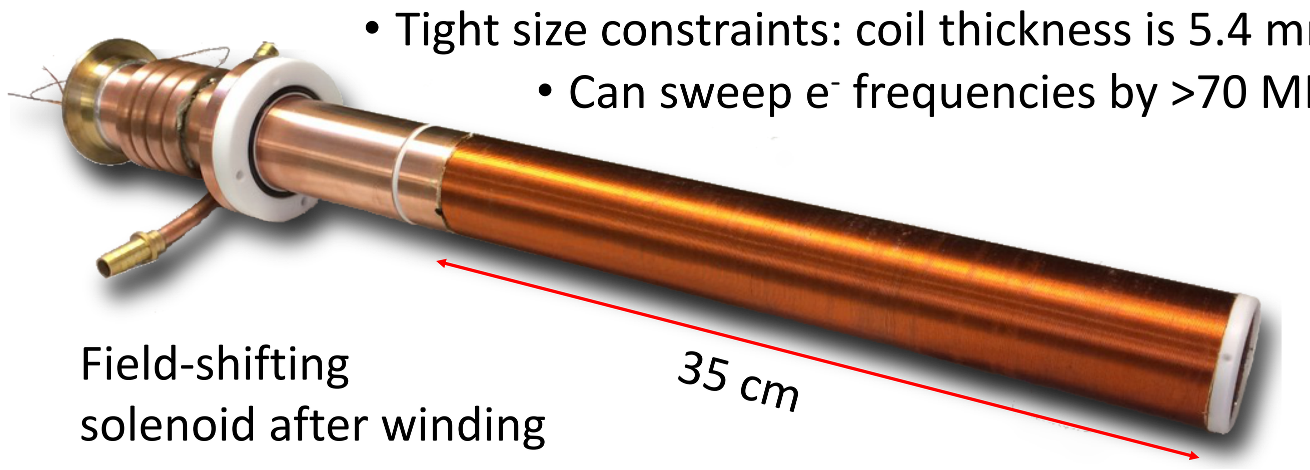
- 5 trap coils available
- 2 trap coils used as independent traps

Linearity Test

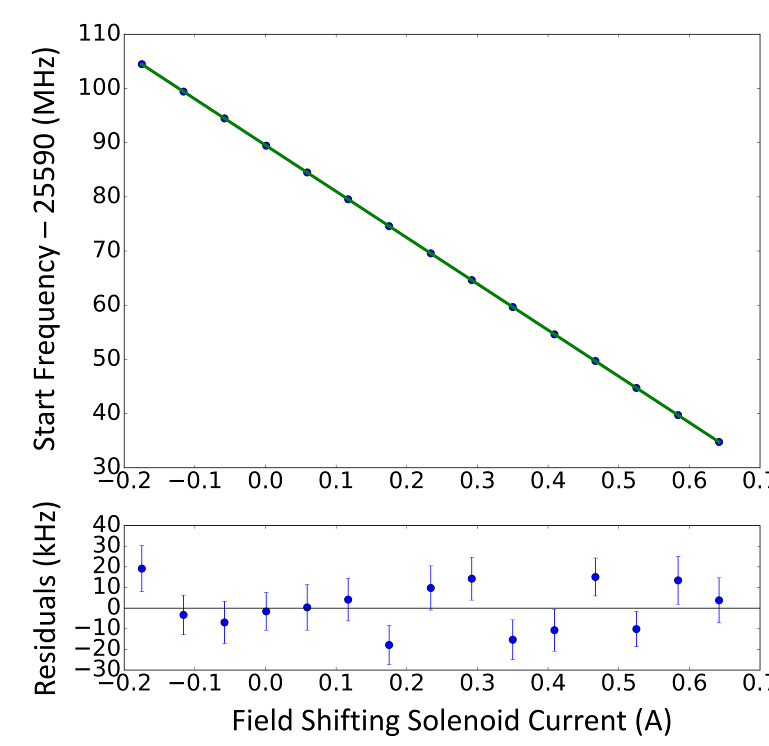
- System response mapped using the 17.8 keV lineshape
- Field-shifting solenoid moved peak across 70 MHz
- Response is linear to within ≈10 kHz

Field Shifting Solenoid (FSS)

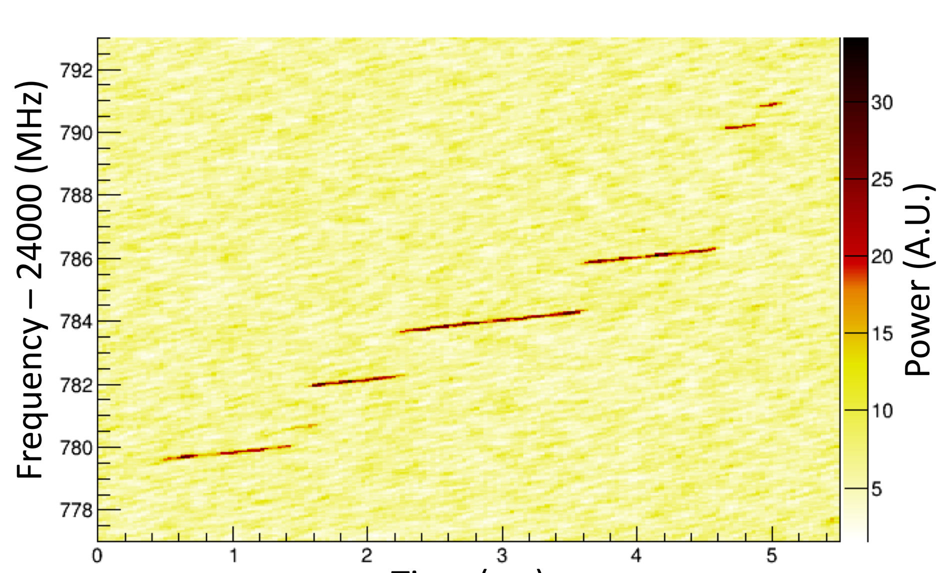
- Long solenoid to uniformly shift the background B field
- Surrounds gas cell, just inside magnet bore
  - Tight size constraints: coil thickness is 5.4 mm
  - Can sweep e$^-$ frequencies by >70 MHz



Field-shifting solenoid after winding



V. Event Reconstruction

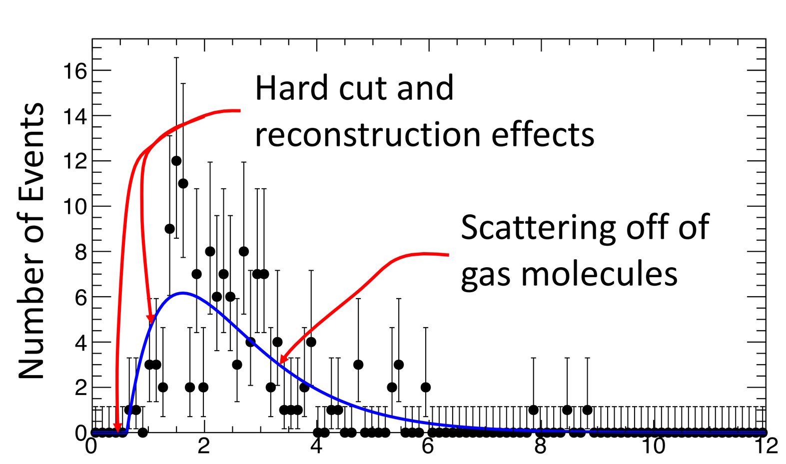


Track & Event Reconstruction

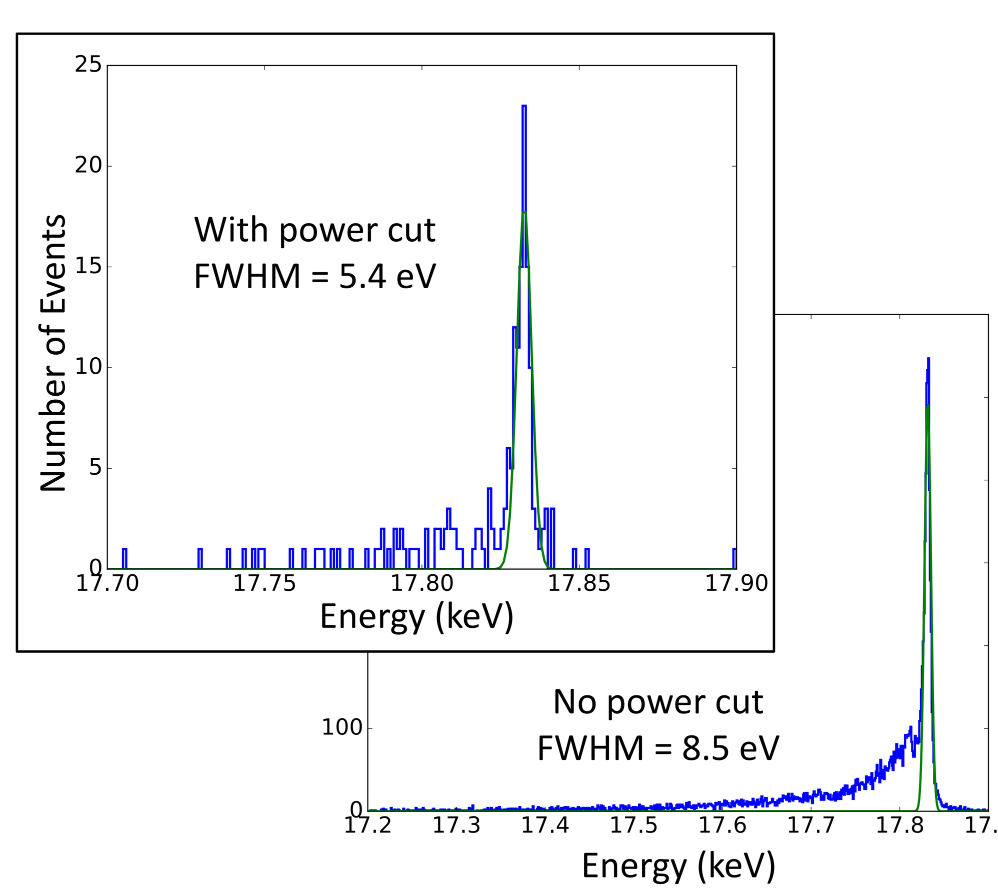
- Short-time Fourier Transform creates spectrograms
- High-power bins are selected and sequentially clustered into tracks
- Tracks are grouped into events by head-to-tail matching
- Initial frequency of the first track is the event start frequency

Track length & gas density

- Characteristic track length determined by scattering on gas molecules
- Model includes reconstruction cuts and scattering time
- Currently developing algorithms for improved short-track reconstruction



VI. ^{83m}Kr Spectrum



17.8 keV electron spectrum

- Magnetic field calibrated by fitting the peak at different FSS currents
- Event frequencies converted to electron energies
- Full spectrum includes a tail from scattered electrons
- Power cut improves the resolution by preferentially rejecting misreconstructed electrons, but is not the final analysis strategy

References & Acknowledgements

[1] B. Monreal and J.A. Formaggio, *Relativistic cyclotron radiation detection of tritium decay electrons as a new technique for measuring the neutrino mass*, Phys. Rev. D **80**, 051301 (2009).

[2] D.M. Asner, *et al.* (Project 8 Collaboration), *Single-electron detection and spectroscopy via relativistic cyclotron radiation*, Phys. Rev. Lett. **114**, 162501 (2015).

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