Electron Capture Spectroscopy and Isotope Production: Research Toward A Neutrino Mass Measurement

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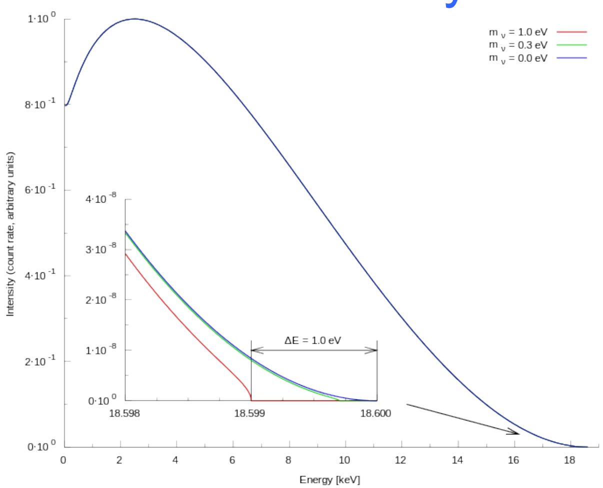
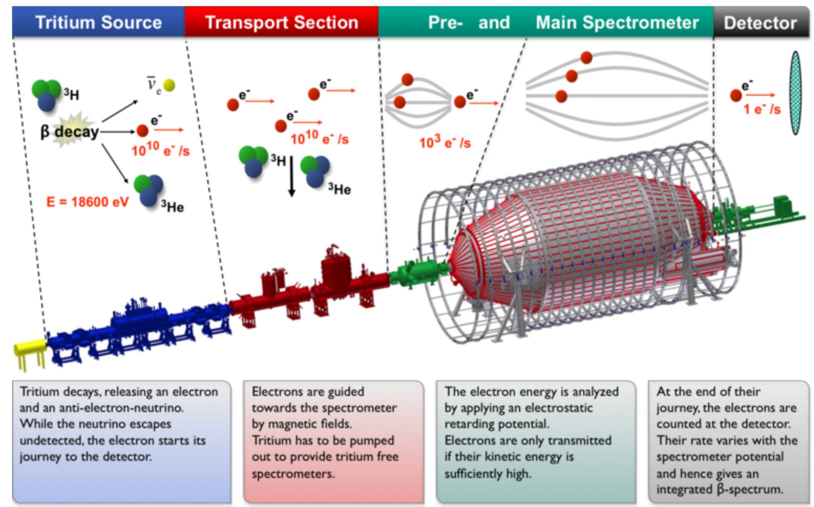
Neutrino Mass via Endpoint Spectroscopy

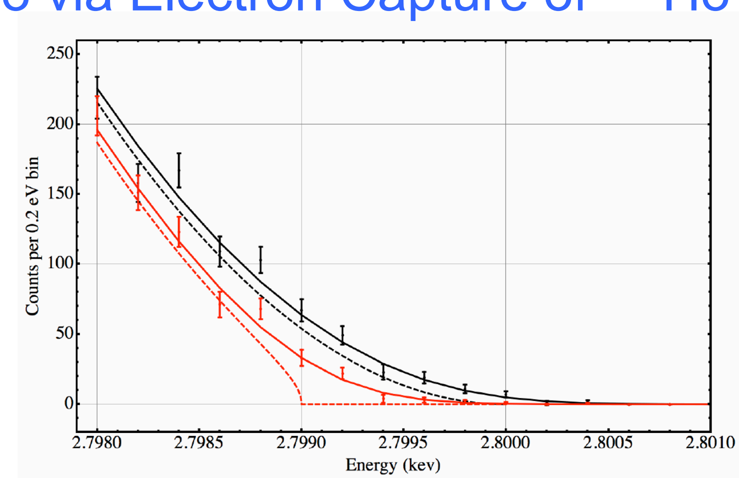
Anti Neutrino via Beta Decay of Tritium





Large Spectrometer - KATRIN

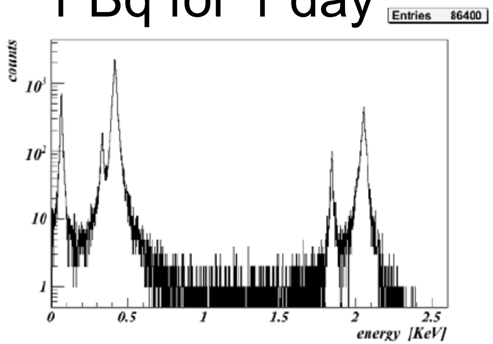
Neutrino via Electron Capture of ^{163}Ho



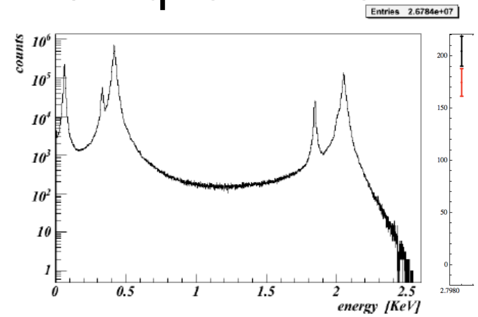
Transition Edge Sensor in a Cryostat

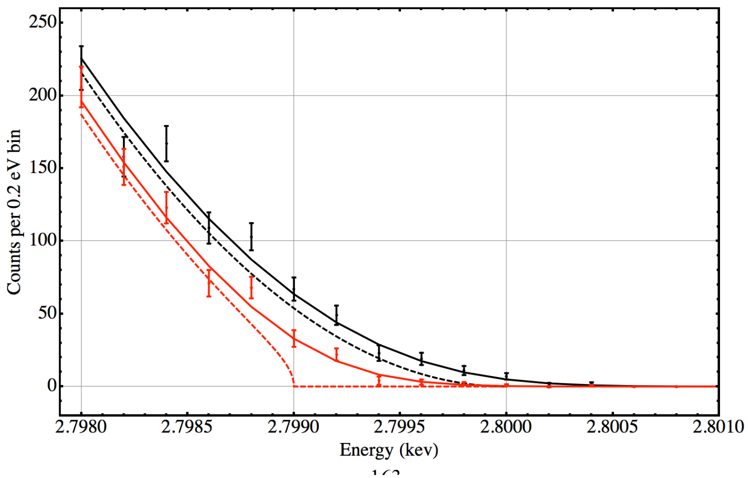
^{163}Ho Endpoint and Neutrino Mass Sensitivity (Simulation)

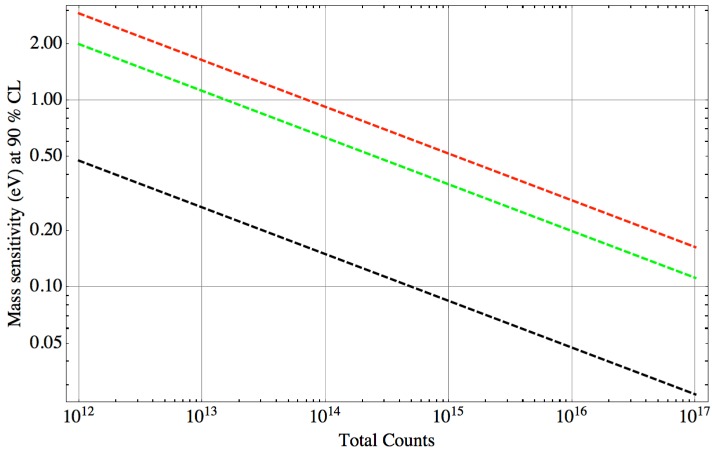
1 Bq for 1 day



10 Bq for 1 month







- Endpoint simulation for 10 ^{14} decays and a spectral resolution of 1 eV

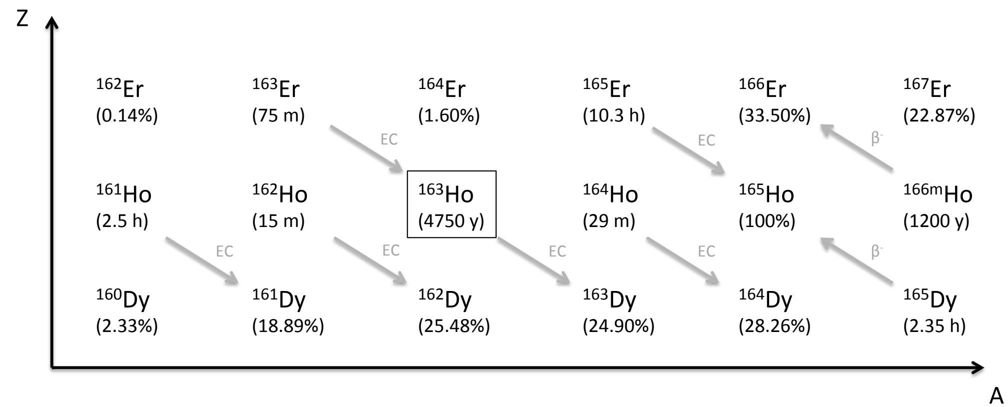
Neutrino mass sensitivity for Q-2.8 KeV (green line)

^{163}Ho Isotope Production

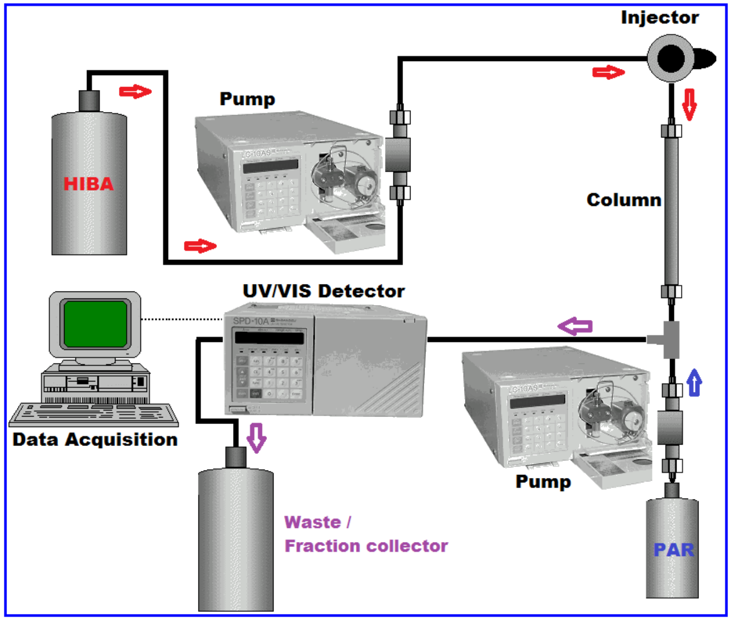
J. W. Engle et al., NIM B, 311 (2013) 131-138

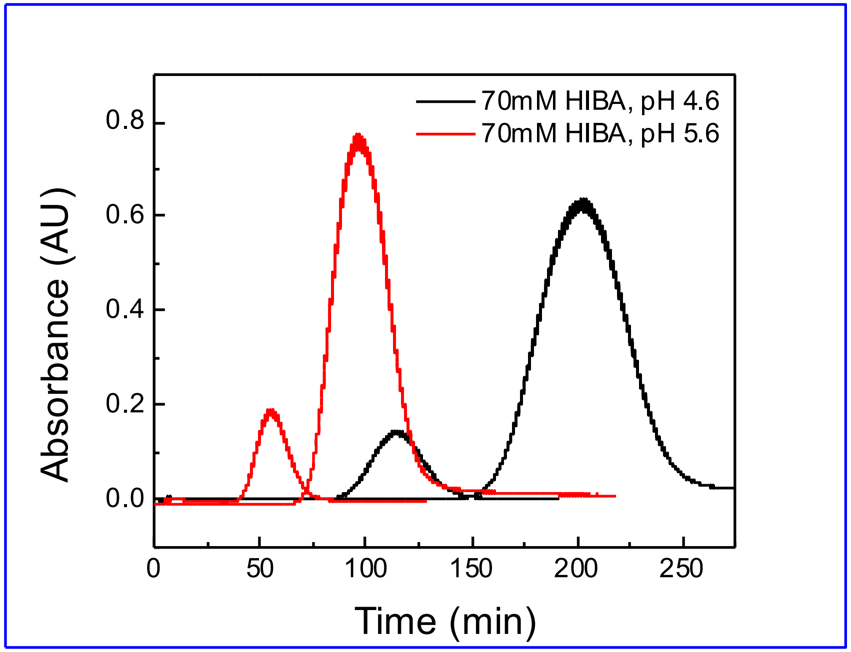
Incident Particle	Target	^{163}Ho Production Rate (atoms/hr)	^{166m}Ho Production Rate (atoms/hr)	^{163}Ho/^{166m}Ho Atom Ratio
(a) 16 MeV p^+	^{nat}Dy	**10^{14}**	10^{4-5}	**10^{9-10}**
(b) 24 MeV p^+	^{nat}Dy	**10^{15}**	10^{6-9}	**10^{6-9}**
(c) 40 MeV α	^{nat}Dy	**10^{13}**	10^{7}	**10^{5}**
(c) 40 MeV α	^{161}Dy	**10^{10}**	10^{3}	**10^{7}**
(d) 10^{14} neutrons/cm^2/sec	^{162}Er	**10^{13-15} (per mg ^{162}Er)**	10^{10-12}	**10^{3-5}**

- Proton irradiation of Dy or neutron irradiation of Er
- Greater radio-isotopic purity is achievable using charged particle irradiations



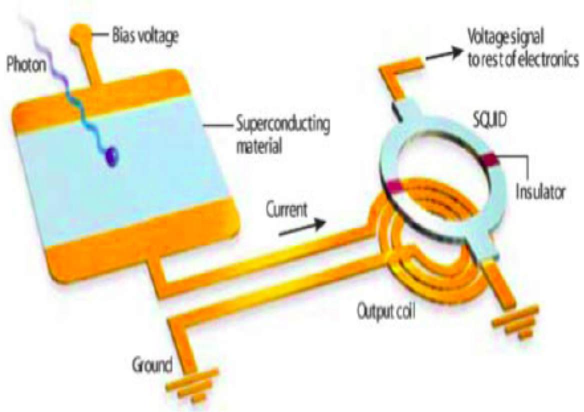
Isotope Separation

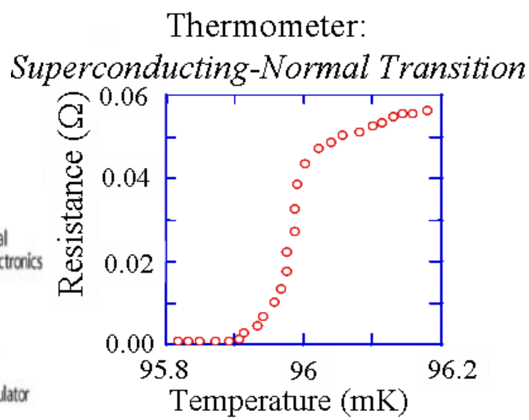


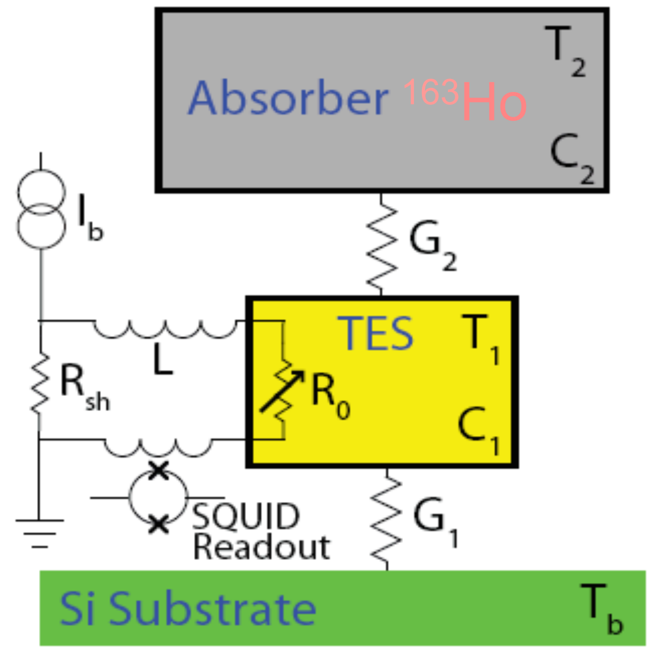


- **Chemical separation to isolate ^{163}Ho from irradiated dysprosium target**
- **High performance liquid chromatography (HPLC)**
  - Cation exchange resin
  - α-HIBA as eluent
  - UV-Vis detection
  - Post column detection reagent 4-(2-pyridylazo)resorcinol

Transition Edge Sensor for Measurement





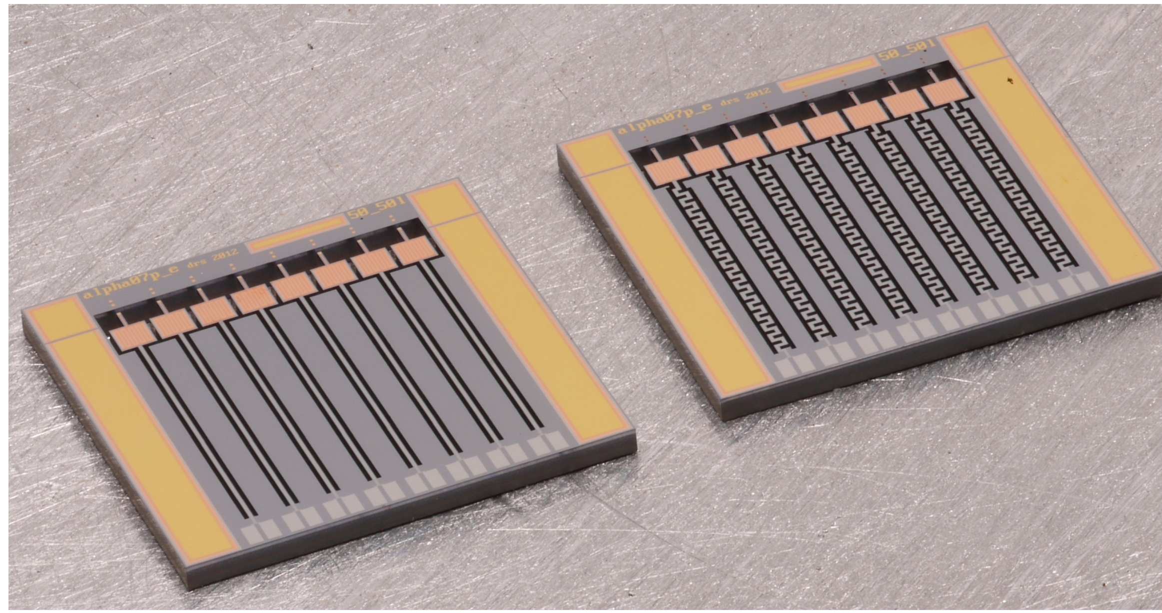


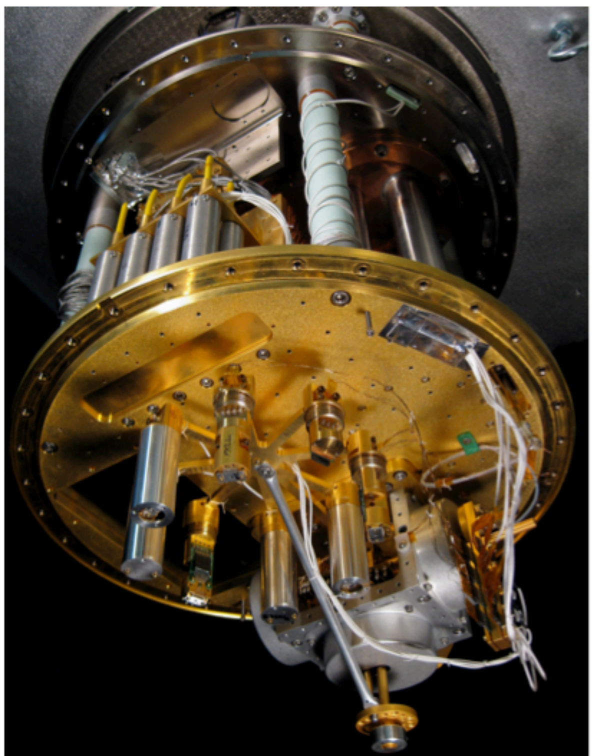
- Superconducting film biased with a constant voltage in the transition region between its normal and superconducting states

- Current flowing through film changes flux in inductively coupled SQUID to produce voltage signal.

$$\Delta E \sim (k_b T^2 C)^{1/2}$$

Cryostat and Dedicated Electron Capture TES

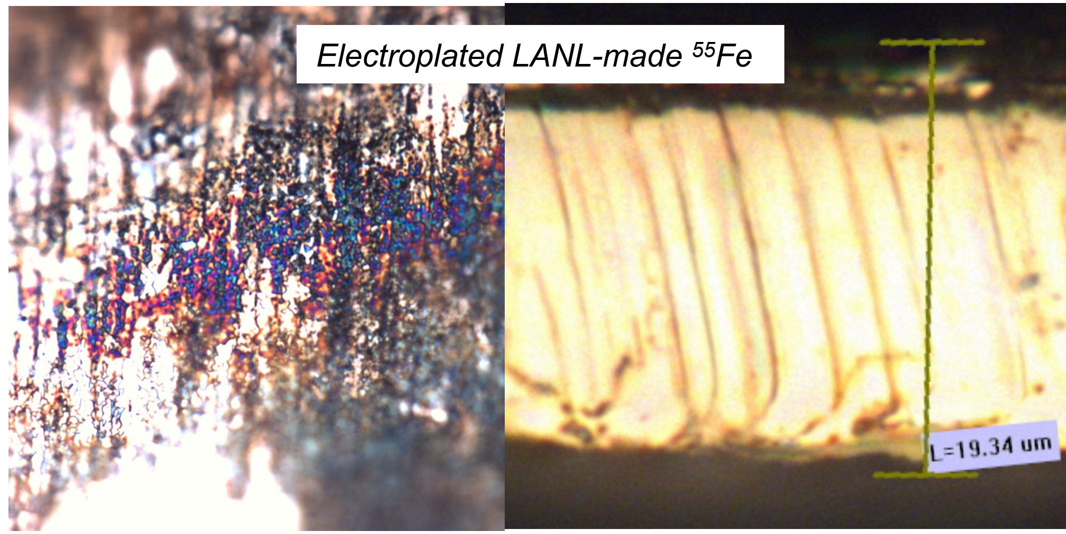


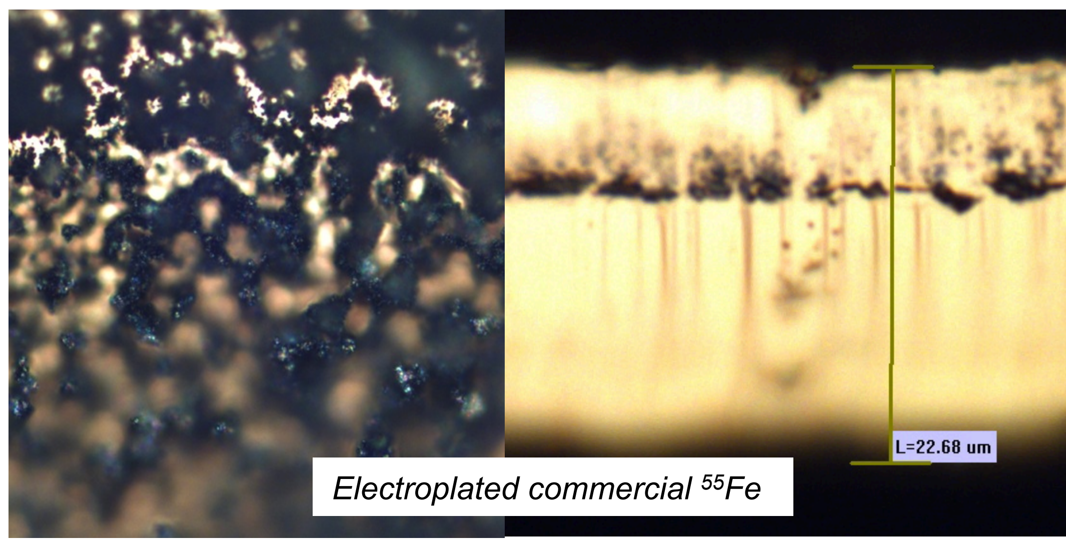


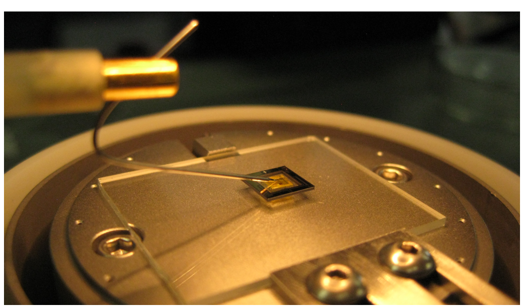
- **Pulse Tube Cryostat**
- **Detectors at 90 mK**
- **EC - TES (350x350 um)**
- **Total C ~ 1pJ/k**

Absorber (Deposition and Diffusion Bonding)

- **Electroplating: metallic, thin, uniform deposition**
- **Pressure (deform Au)**
- **Heat (400°C)**
- **Time (1 hr)**
- **Inert atmosphere**
  - Avoid oxidation of embedded material

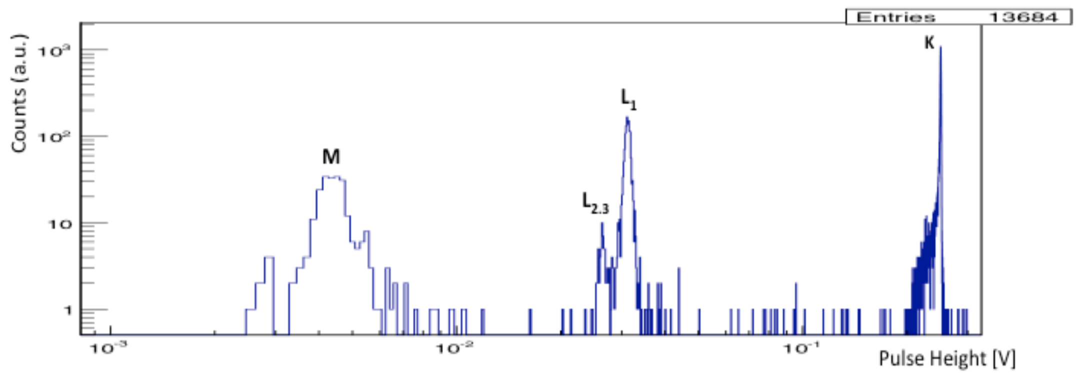


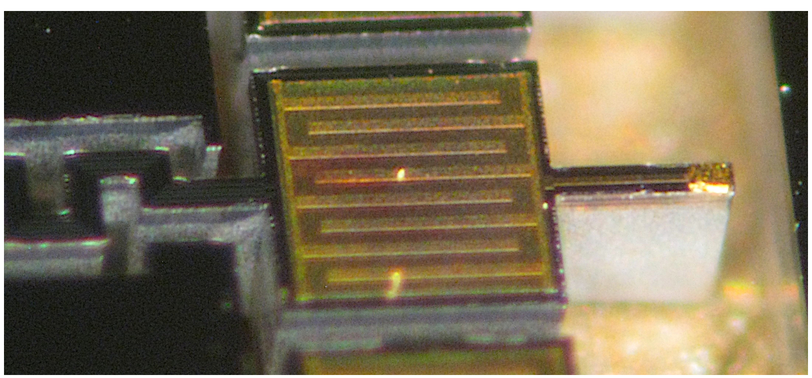


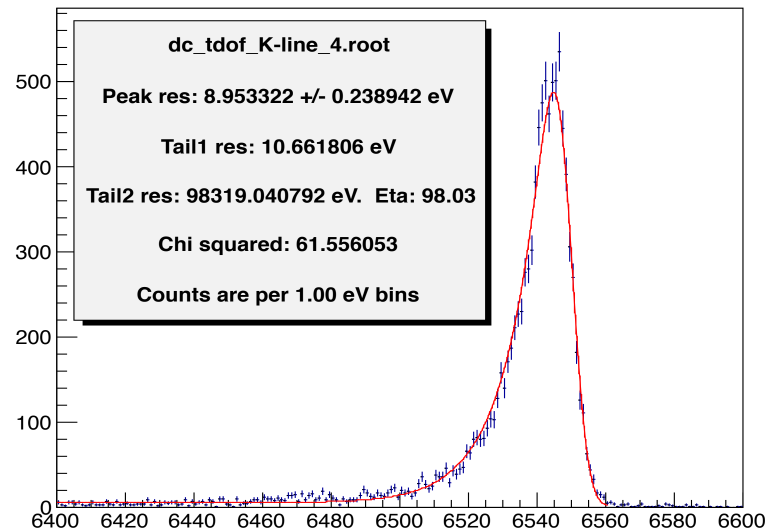


Electron Capture Spectroscopy of embedded ^{55}Fe

- **Electroplated** ^{55}Fe in diffusion bonded Au
- Absorber C ~0.17 pJ/K, 33x45x18 μm, diffusion bonded to TES structure
- Total C ~1 pJ/K
- 9.0+-0.2 eV Resolution







SUMMARY

- **Isotope Production via Proton Irradiation**
- **Isotope Separation via HPLC**
- **Transition Edge Detector with SQUID readout in Cryostat**
- **Dedicated Electron Capture TES with total C of ~1 pJ/K**
- **First test with surrogate EC uses ^{55}Fe**
- **Resolution obtained better that 10 eV**
- **Outlook**
  - First measurement with ^{163}Ho planned for this year
  - Increase channel count by RF multiplexing