Multiplexing Readout for HOLMES

motivation, design, and performance

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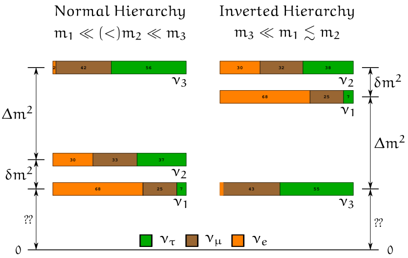
Contents

Briefest possible introduction to neutrinos

neutrinos

- neutral fermions: one for each charged lepton
- different masses
- might be their own antiparticles



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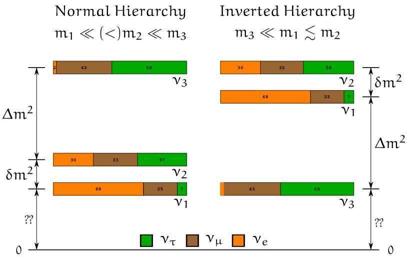


The history of the neutrino mass

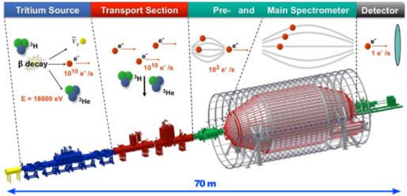
- Thought massless until oscillations were discovered in 1960's
- Oscillation measurements only tell mass splittings
- Cosmology measures average over all flavors, $M_\Sigma = 0.32$ eV
- Direct measurement (Mainz) $M_{\nu_e} \leq 2.2$ eV
- Implications to cosmology, majorana equation, see-saw mechanism ...

Direct measurements of m_ν

Can't measure neutrinos directly, measure other elements of weak interactions.

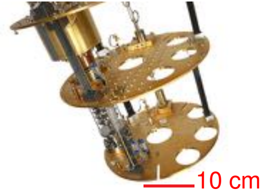
Beta Decay

- KATRIN, Project 8
- $n \rightarrow p + e^- + \bar{\nu}_e$
- use tritium
- measure electron energy
- **do not measure** nuclear recoil, atomic effects, etc.

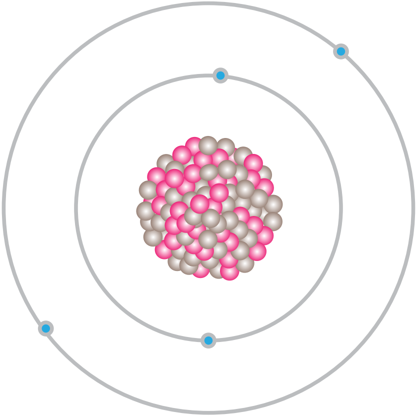


Electron Capture

- ECHo, HOLMES, NuMECS
- $p + e^- \rightarrow n + \nu_e$
- use holmium-163
- source inside detector
- measure the decay's **total energy**, Q

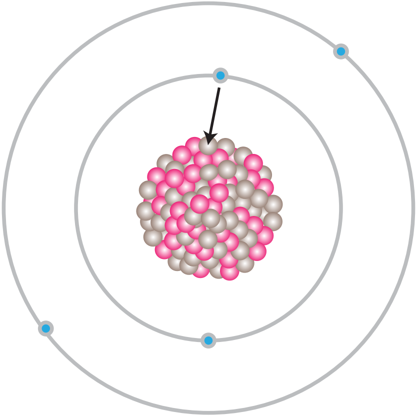


Q-spec, electron-capture, and the neutrino mass



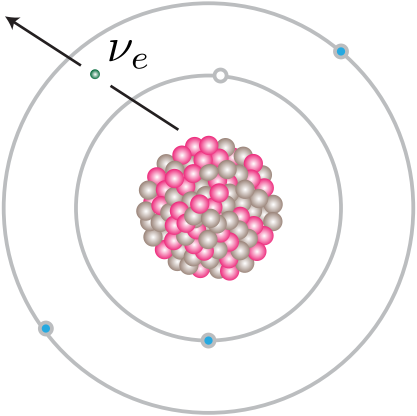
nucleus with too many protons

Q-spec, electron-capture, and the neutrino mass



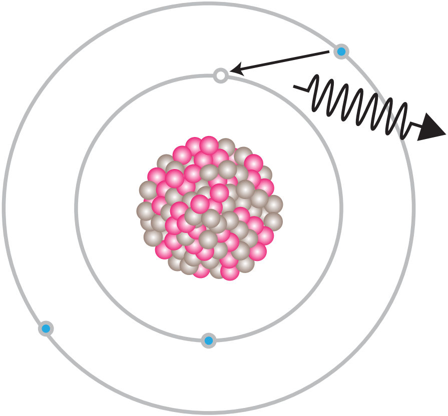
captures an inner electron

Q-spec, electron-capture, and the neutrino mass



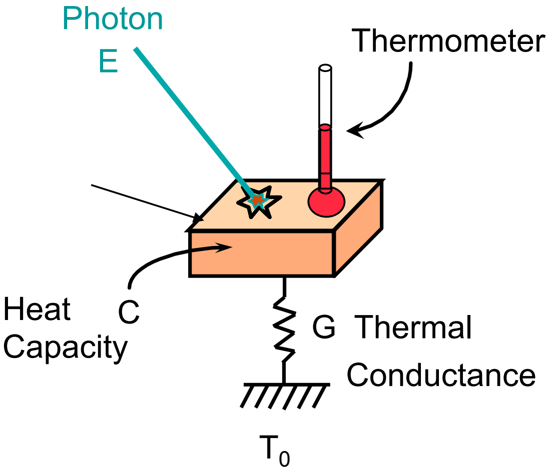
$$p + e^- \longrightarrow n + \nu_e$$

Q-spec, electron-capture, and the neutrino mass

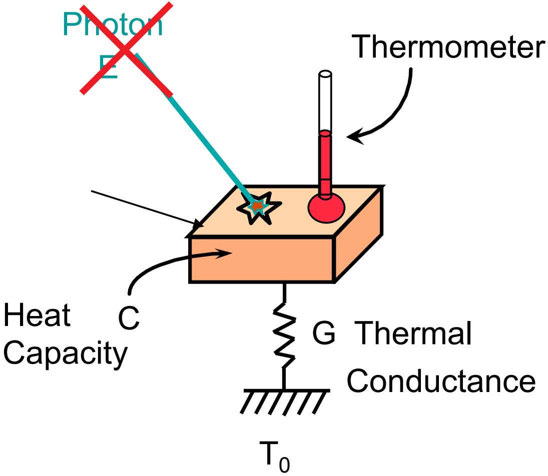


daughter atom in excited state: decays with x-rays, etc.
capture all the non-neutrino energy to infer neutrino mass

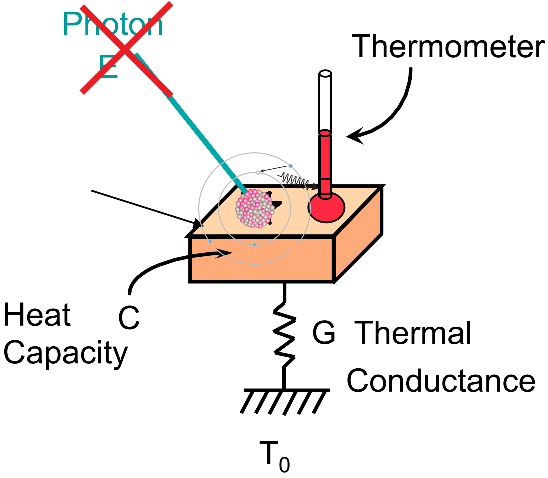
Q-spec, electron-capture, and the neutrino mass



Q-spec, electron-capture, and the neutrino mass



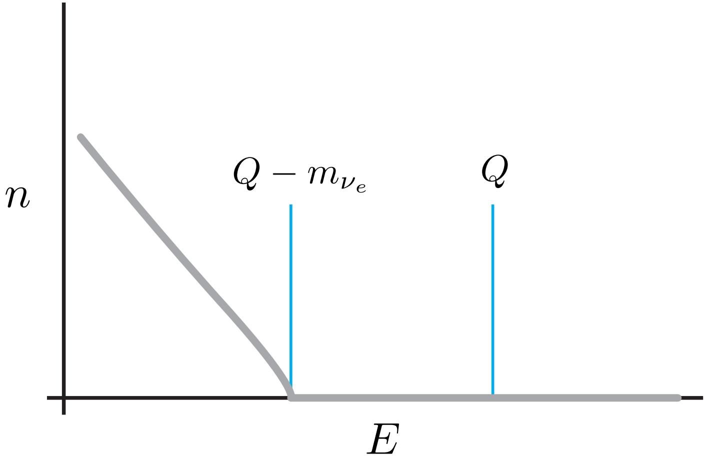
Q-spec, electron-capture, and the neutrino mass



Decaying elements is embedded inside detector

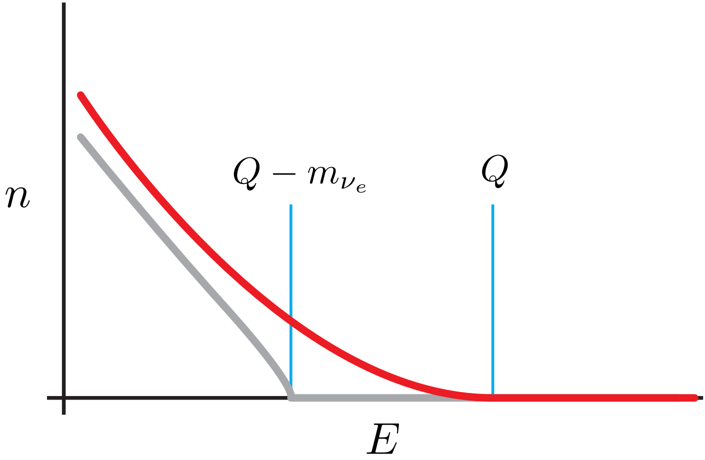
total energy of decay is captured
except neutrino

careful look at the spectrum endpoint



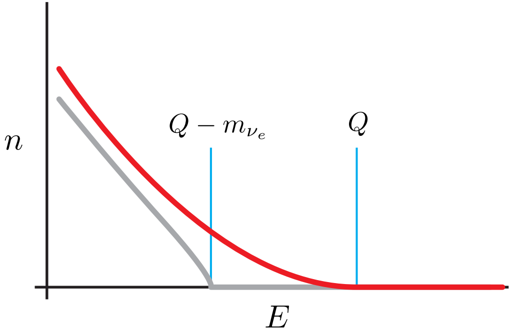
spectrum edge cuts off m_{ν_e} away from Q

careful look at the spectrum endpoint



m_{ν_e} and ΔE are both eV scale and Q is keV scale (and unknown)

careful look at the spectrum endpoint

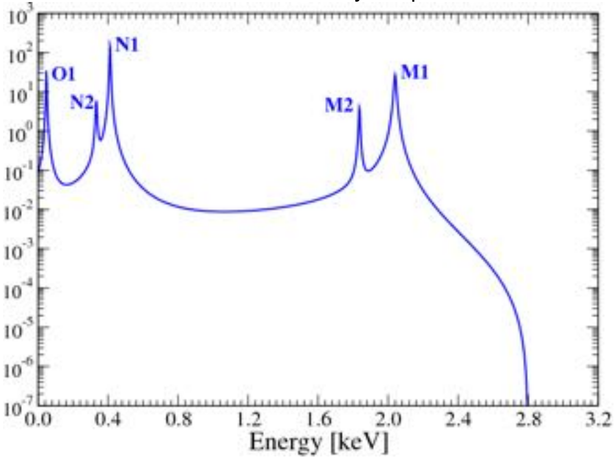


$${}^{163}_{67}\text{Ho} + e^- \longrightarrow {}^{163}_{66}\text{Dy} + \nu_e,\ Q \sim 2.8\ \text{keV}$$

requires many ($\sim$1,000) state of the art detectors ($\leq$ 5 eV at 3 keV)
with embedded ^{163}Ho
multi-year acquisition time

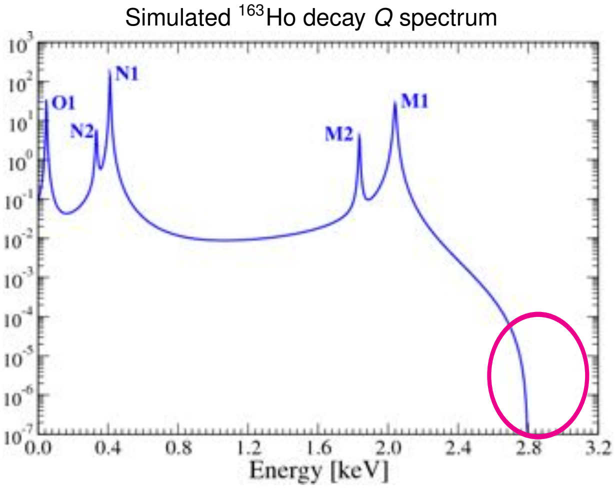
Pile-up in HOLMES

Simulated ^{163}Ho decay Q spectrum



- Endpoint events vanishingly rare

Pile-up in HOLMES



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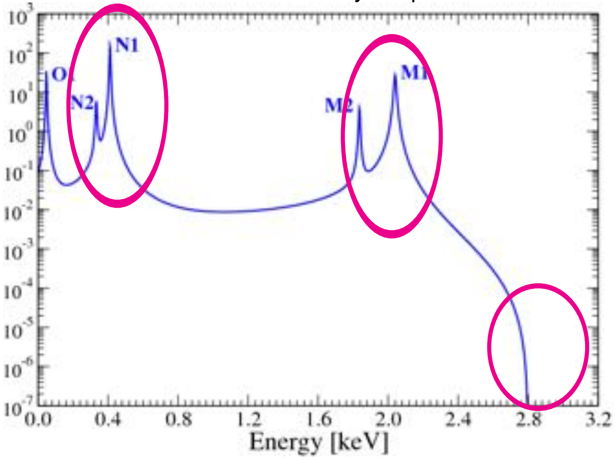
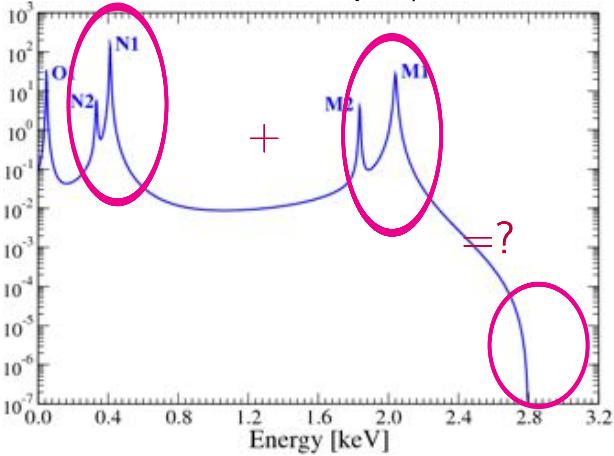


- Endpoint events vanishingly rare
- Two common events could be coincident enough to fake a rare one.

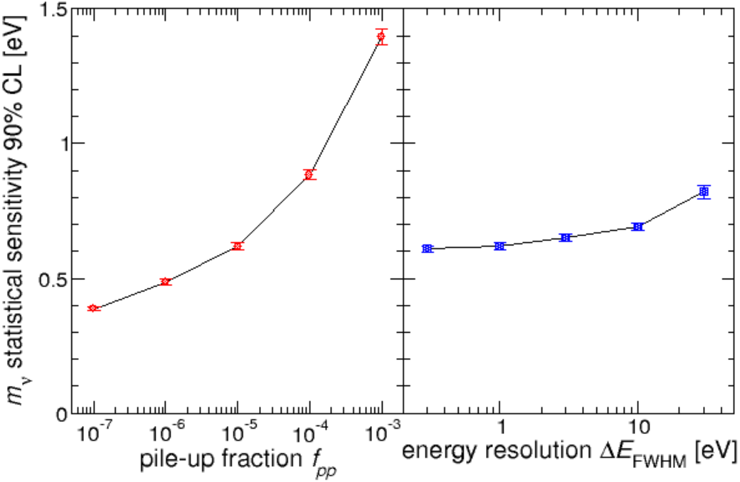
Pile-up in HOLMES

Simulated ^{163}Ho decay Q spectrum



- Endpoint events vanishingly rare
- Two common events could be coincident enough to fake a rare one.
- Identification depends on both sampling and rise time.
- B. Alpert et al. J Low Temp Phys (2016) 184: 263. doi:10.1007/s10909-015-1402-y

Pile-up in HOLMES



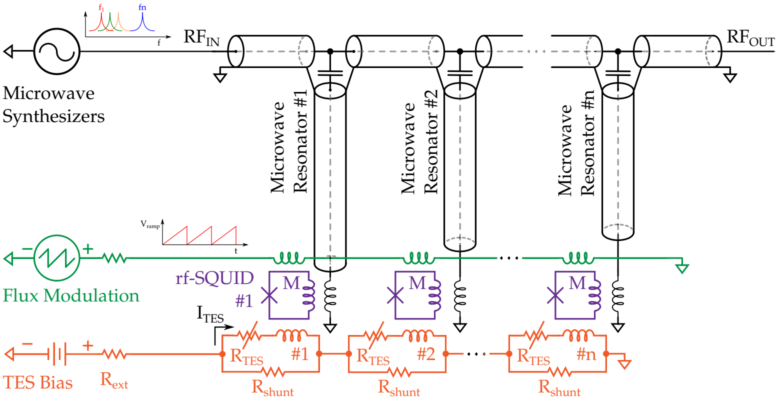
Final sensitivity on m_{ν_e} depends mostly on statistics and pileup.
Energy resolution only a slight concern.

Multiplexing Choices

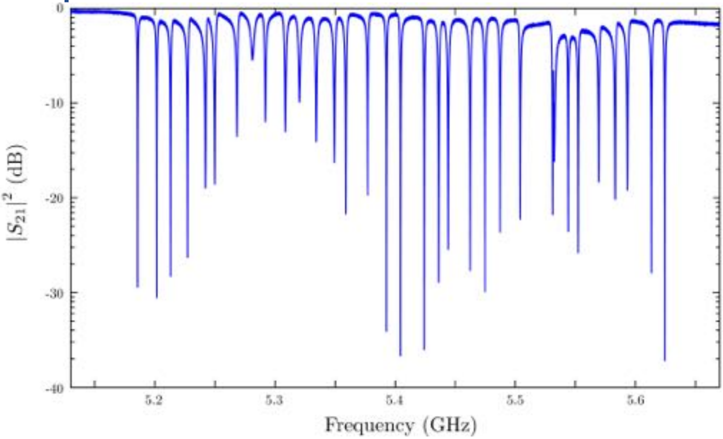
Constrained by a finite amount of time, bandwidth, and ^{163}Ho, HOLMES is targeting:

- 1000 pixels
- 300 counts per second per pixel activity
- 500 kHz sampling rate

Multiplexing Scheme

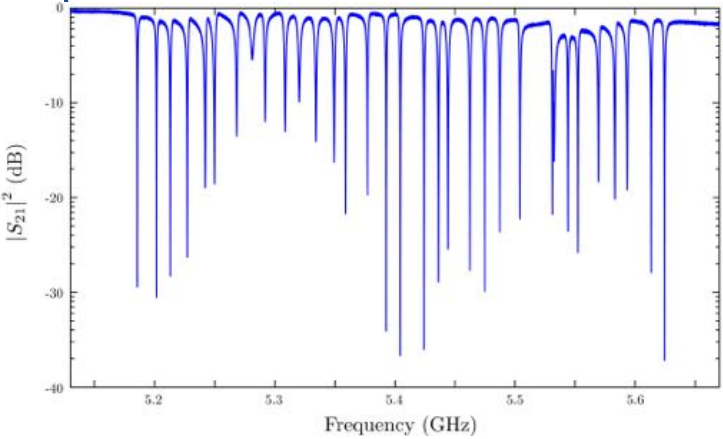


Multiplexer



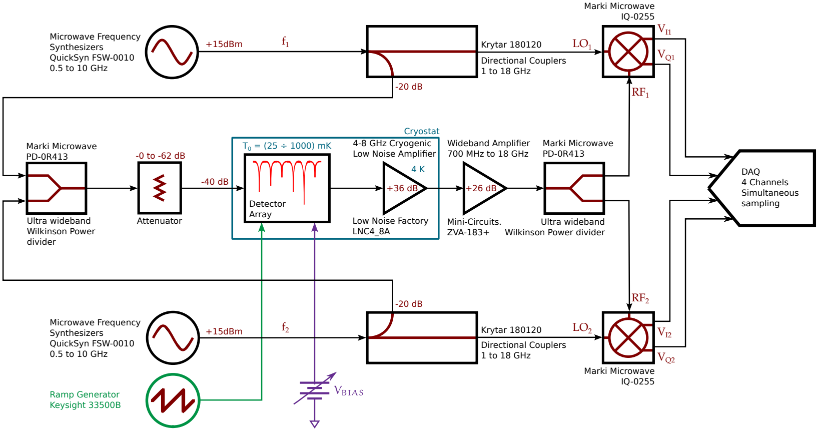
- 2 MHz per channel full bandwidth
- allows 32 channels to fit onto a 550 MHz ROACH2 ADC

Multiplexer



- 2 MHz per channel full bandwidth
- allows 32 channels to fit onto a 550 MHz ROACH2 ADC
- $2\Phi_0$ ramp $\rightarrow$ corresponds to a sampling rate of 500 kHz
- $1\Phi_0$ ramp $\rightarrow$ possibility of 1 MHz sampling rate?
- should handle slew rates up to < 1 A/s

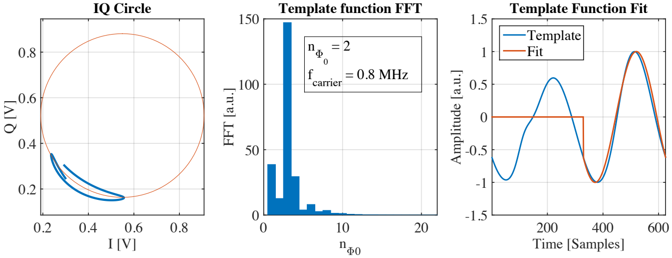
Present Homodyne Setup



Dual Homodyne setup, can record 2 pixels at 500 kHz

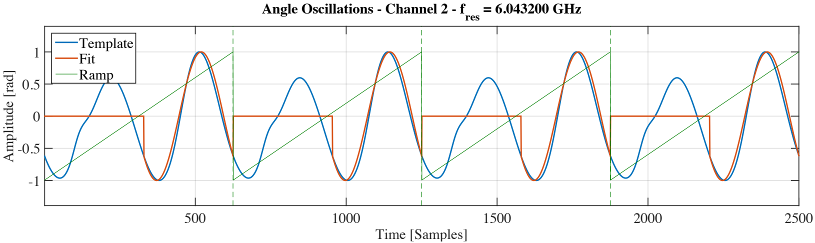
ROACH2 to be deployed soon - see poster by J. Gard 2EPo2B-11 [111]

Templated Oscillations



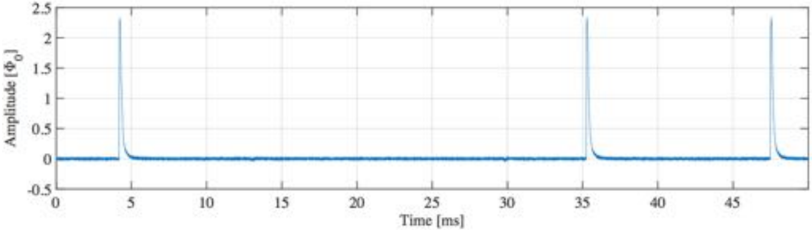
A template is created from averaged response to the flux ramp
Response is very nearly Sinusoidal

Phase Offset from Template



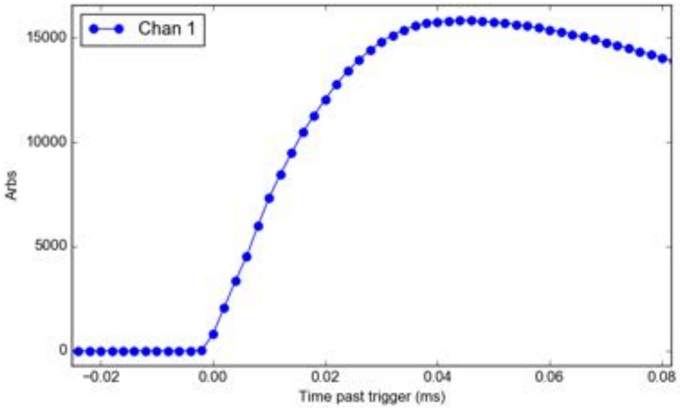
For each ramp period, response is fit against the template
First Φ_0 has transient, is not used

Demodulated signals



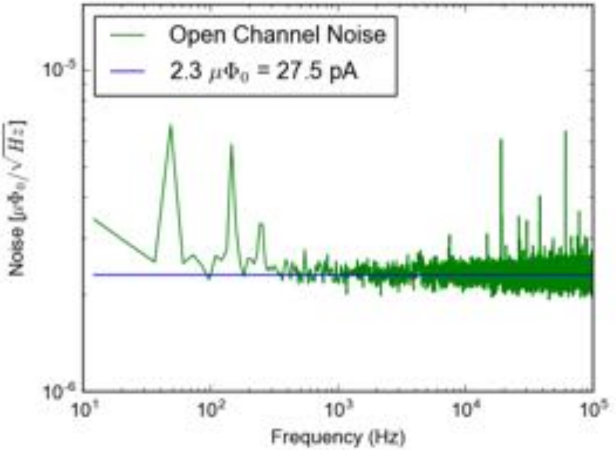
Demodulated time stream from one detector, Fe55 X-ray source.

Demodulated signals



- At $T_{10-90} \approx 25\ \mu$s, 500 kHz gives you $\sim$12 points on the rising edge
- Rise time limited by arrival time effects, not readout slew rate.

Noise Performance



- Demodulated open resonator shows good noise performance
- ($\approx$ 27 pA/$\sqrt{\mathrm{Hz}}$)

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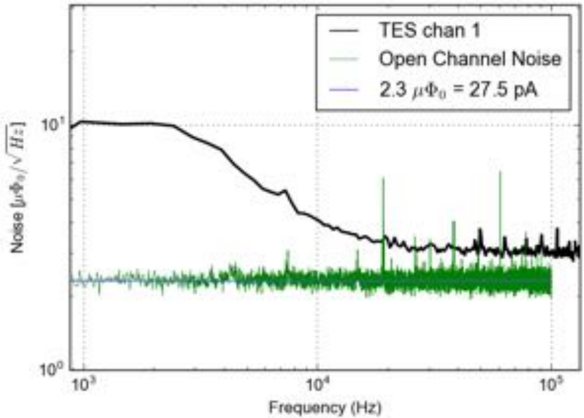
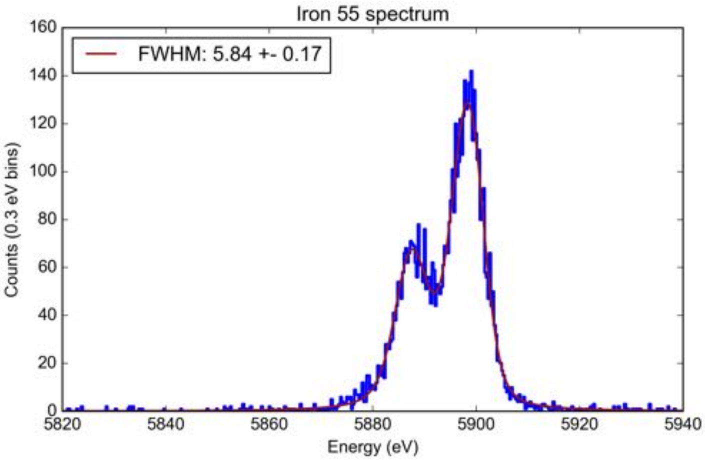


- Demodulated open resonator shows good noise performance
- ($\approx$ 27 pA/$\sqrt{\mathrm{Hz}}$)
- TES noise still dominates over readout

Resolution Results



- 6 eV FWHM resolution demonstrated at 5.9 keV
- First Fe55 peak separation with μmux ?

Conclusions

- Resonator bandwidth and detector parameters all motivated by count rate
- HOLMES is a demanding application for this new readout
- Most of requirements are shared by next generation x-ray instruments
- ROACH2 readout and full arrays to be tested soon

Thank You!